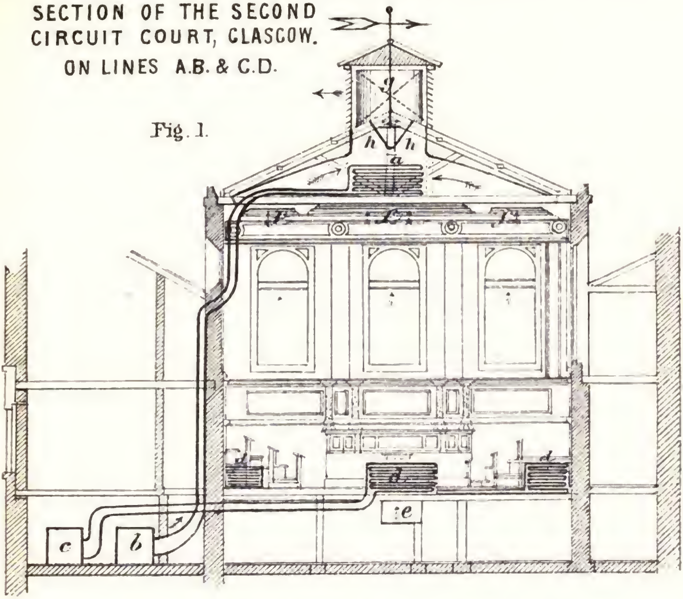

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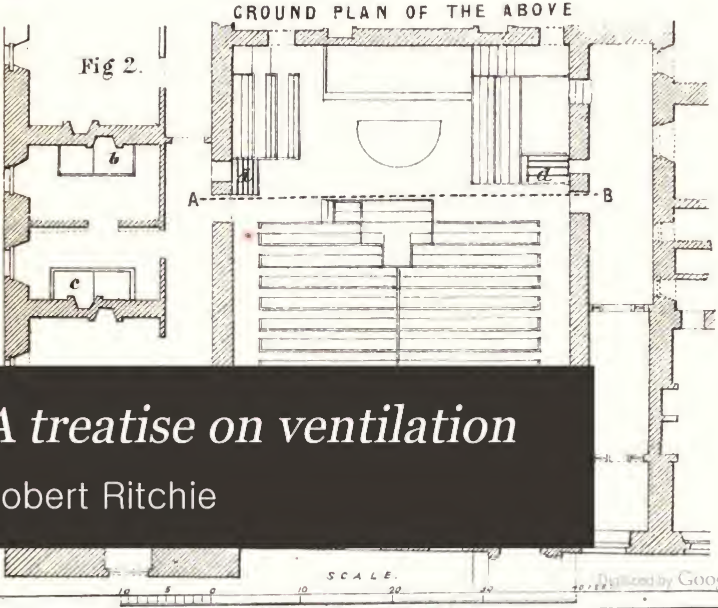

Fig 2.

A treatise on ventilation

Robert Ritchie

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A

TREATISE ON VENTILATION,

NATURAL AND ARTIFICIAL.

BY

ROBERT RITCHIE, C.E.

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PAST VICE-PRESIDENT OF THE ROYAL SCOTTISH SOCIETY OF ARTS;
AUTHOR OF "RAILWAYS: THEIR RISE, PROGRESS, AND CONSTRUCTION;"
"THE FARM ENGINEER, WITH REMARKS ON THE VENTILATION
OF FARM BUILDINGS;"
AND VARIOUS PRIZE ESSAYS—ON THE VENTILATION OF FACTORIES,
SHIPS, &c. &c. &c.

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PREFACE.

THE groundwork of this book formed the matter of an article for the Cyclopædia of the late Dr. Nichol, Professor of Astronomy in the University of Glasgow, who in that work on the Physical Sciences, under the head "Ventilation," (p. 830), in the Appendix, has the following complimentary paragraph:—

> "At the close of "HEATING OF BUILDINGS," p. 385, reference is made to a sequel to it which we had assigned to the heading "VENTILATION." An admirable practical essay on this most interesting subject has just reached us from Mr. R. Ritchie, Civil Engineer, Edinburgh, Assoc. Inst. C. E. L. (the author of article on HEATING), which we should most gladly have printed in addition to the general notice in the text, had space and the press of time permitted. It contains so full and scientific an analysis and criticism of all that has been done and proposed on this most essential subject, that we cannot pass the opportunity of expressing the hope that Mr. Ritchie will extend it and publish it as a substantive work. Mr. Ritchie has already obtained many distinctions from learned societies on account of his labours in this very important field."

Induced by this recommendation, the original paper has been expanded into the present work, in which is comprised within a moderate space not only a synopsis of the various plans, systems, and adaptations proposed for effecting Ventilation, but also as much theoretical, scientific, and practical information as will enable those interested to form an opinion on the science and art of ventilation, and to distinguish between correct and false principles, which latter have led to many of the various forms of ventilators now in use. In order that this information may be obtained, many of the plans and contrivances which have been proposed and adopted in past and present times to effect ventilation both by natural or self-acting and by artificial means, are brought under review, so that a clear conception may be formed of their advantages and disadvantages when required to effect a definite result.

For simplicity and distinctness the work has been divided into five Chapters. The first chapter is devoted to the consideration of ventilation in its chemical and physiological relations; in the second, natural or spontaneous ventilation is treated of; and in the third, fourth, and fifth chapters, forced ventilation, and a number of the artificial and mechanical agents employed to effect this, are described. In the works of others on ventilation where a systematic arrangement is made, it has been the buildings or other places which have been so described; but in this, the different agents or instruments to effect ventilation have been classified, whilst a description of the buildings &c. has not been overlooked. The subjects treated of are illustrated by numerous plates and woodcuts; and for convenience, a Summary of the whole treatise is subjoined.

In treating a subject on which so much diversity of opinion exists, not only in theory but in practice, it has been the desire of the author, while giving his own views and opinions, that the works and labours of others should not be overlooked.

The importance of ventilation was prominently brought under public notice in 1835, by the appointment of a Select Committee of the House of Commons, and the valuable evidence on ventilation and acoustics then taken was published for the benefit of the public, in the form of a Parliamentary Report. A stimulus was thus given to the investigation of the subject, which subsequent Parliamentary Reports, and Reports from the Board of Health, have kept up; so that general attention has been turned to the consideration of the ventilation of public buildings, dwelling-houses, manufactories, mines, ships, &c. While much has been done in recent years, there is still much left undone; and until ventilation and other sanitary measures are more intimately combined, and a systematic process of ventilation applied to all classes of buildings, the science is still incomplete. For it has been truly observed, that "vitiation of the atmosphere from overcrowding, and the absence of proper ventilation in individual apartments, produces in the rural districts the same diseases that arise from the same causes in a town population." *

In a subject so extensive, and with which the names of so many inventors are associated, it has been endeavoured to treat it impartially and to do justice to all. Amongst the earliest who brought science to bear on ventilation in this country was the late Thomas Tredgold, C. E. Since his time no one has done more to advance this subject, or give it the importance it deserves, than Dr. D. B. Reid, whose thorough chemical knowledge has been brought to bear upon practical ventilation with much advantage to the public. Nor must the labours of the late Dr. Birkbeck be overlooked, nor those of Professors Brande and Farraday, Mr. Chadwick, Mr. Gurney, and others, nor the assiduity with which Dr. Arnott has for years brought forward inventions for the public benefit.

This Treatise, being the work of one who is practically engaged in the execution of various plans for ventilation, will, it is hoped, be esteemed the more deserving of public attention, as being based not upon theory alone, but on practical experience.

16 *Hill Street, Edinburgh*,
June 1862.

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* From Report by "Health of Towns Commission."

ERRATA.

Page 23, first line from top, *for* acid *read* air.
" 75, foot note, *for* patient *read* patent, *and*
for A. W. *read* A. M.
" 92, bottom line, *for* 31 *read* 51.
" 93, second line from top, *for* 00 *read* 51.
" 106, *for* fig. 14 *read* 15, *and for* fig. 15 *read* 16.
" 120, third line from bottom, *for* 1655 *read* 1665.
" 154, first line, *for* 1859 *read* 1854.
" 188, Heading of Chap. V., *for* OTHER *read* DIFFERENT.

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CHAPTER I.

VENTILATION AS REGARDS SALUBRITY.

VENTILATION and salubrity are so conjoined, that it is impossible to consider the one without keeping the other in view. The necessity of pure air for health in cities, in public buildings, hospitals, prisons, dwelling-houses, mines, factories, workshops, and in the more humble abodes of artizans, must be apparent to every one interested in the cause of science and human progress, hence the importance of ventilation in a sanitary point of view, which of late years has had public attention directed towards it, from the General Board of Health—from the Registrar-General's, and various Sanitary, Statistical, and Parliamentary Reports. The importance of the subject as regards health can hardly be over-estimated.

The word ventilation, in so common use, is derived from the Latin word *ventilo*, to ventilate, or to blow, fan, or winnow; and in its most ordinary signification implies movement of air with reference to the removal of impure atmosphere.

The subject may be divided into two heads—External and Internal Ventilation—the latter is the sense in which the word is generally understood, and in which it is to be used in this Treatise. Ventilation thus applied, means the act of providing, in any confined area, or in places where the air has been vitiated from various causes, an adequate supply of pure air for the renovation or renewal of the interior or confined air—or ventilation may be termed the art of removing impure and supplying pure air.

In natural ventilation, the principle by which the mobility of the air arises, is from the fact, that cold air is heavier than warm air, bulk for bulk—the conducting property of the air is slow, and thus the cold has the tendency to sink downwards, passing through and displacing the warm and lighter air, which is forced upwards. Thus a constant change or movement of the air goes on by natural laws promoting salubrity. The effect of the solar rays is to cause rarefaction of the air, produce winds, and the great movement of the atmosphere from the poles to the equator. The motion of the air is also accelerated by the difference of temperature between day and night—the different degrees of heat radiating from the earth's surface, and the effect of heat and cold varying with the earth's annual motion round the sun.

It must be obvious, therefore, as regards health, that no obstruction should be made by man to retard the operation of the natural laws of ventilation, by which every locality where he is domiciled is more or less benefited.

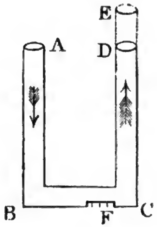
The same principle of mobility which regulates the movement of the external air, regulates the renovation of the interior air of buildings. A slow movement of the air may be effected, or a current may be produced, so as to replace, with fresh air, the atmosphere which has become vitiated in close places. To induce this current without its being offensive, is the object of ventilation, and this is sometimes produced by artificial methods, but more frequently it is attempted by natural means. The certainty of the rate of velocity of the current to be maintained, is the point which will lead to the adoption of the agent to be employed to produce the motion. Thus in mines, where a uniform and constant velocity of the air is requisite—the air generally moving at the rate of 3 to 4 feet per second, and where from 15 to 20 cubic feet per minute are required for each man employed—an artificial agency to produce this current is of vital importance. But to obtain a renovation of the air in places where the vitiation is inconsiderable, by taking advantage of the principle of motion in the particles of air, and its slow conducting properties, from which the colder and heavier falls through the warmer and lighter air, and forces it upwards, there may to a certain extent be produced in houses what is termed spontaneous or self-acting ventilation; for a slight alteration in the specific gravity of the air produces motion of its particles. The density of gaseous bodies is inversely, as their expansion by heat, and by taking advantage of and keeping in view this principle, a movement or current of air is obtained. But as the air is a fluid pressing in all directions, and is easily affected by various causes, in close, still, and gloomy weather, the efflux of the interior impure air to produce effective ventilation is hardly attainable. Also, in crowded apartments and close places, natural ventilation is not sufficient to effect the object desired. Artificial means, therefore, become requisite, to obtain a thorough renovation of the air.

The inconvenience which arises in crowded rooms from ventilating by means of open windows, and air inlets, whether at the ceilings or at the sides of the rooms, is known to every one; hence people, rather than run the risk of getting colds, from being exposed in winter to chill offensive currents, will submit to breathe the impure air of the room. The inlet of fresh air into rooms thus becomes a matter of essential consideration in the science of ventilation, and is perhaps one of the most difficult problems, upon the proper solution of which comfort is dependent. But much can be done by mechanical contrivances to remove vitiated air in close places. Sanitary regulations ought therefore to insist upon its constant renovation. Numerous contrivances, of different degrees of utility, afford in a great measure the means of doing so. Still, no plan can be deemed properly adapted to attain the object, which does not also provide for the supply of fresh as well as for the extraction of vitiated air, and which does not also keep in view the hygrometrical condition of the air when ventilation is required. Whatever may be the agent employed to ventilate a building, there should be at least no risk attending its use, and care should be taken that a greater evil may not be produced than that which is sought to be removed.

PROPERTIES OF ATMOSPHERIC AIR.

In order to have a true estimate of the real importance which attaches to the science or art of ventilation, it may be proper, even though perhaps it may be deemed superfluous, to state a few facts connected with the properties of the atmospheric air, by a knowledge of and attention to which, much may be done to obtain the desired object. Thus the law by which the expansion of air and other gases by heat is regulated becomes important—namely, that they dilate or expand, whether in motion or at rest, nearly uniformly as the temperature is increased. By the estimate of Gay Lussac and others, 1000 cubic inches of air at 32° of Fahrenheit's thermometer, when raised to 212° F., is increased in bulk to 1375 cubic inches. The increase of temperature between 32° and 212° is 180°, and the increase in volume is 375 parts in 1000, or $\frac{3}{8}$ of the whole bulk; and as the expansion is uniform, the increase of volume for 1° F. will be found by dividing 10 times 375 (or 3750) by 180, which will give an increase of $20\frac{5}{6}$ parts in 10,000 or ·00208 parts in 1000; the decimal ·00208 being found by dividing $20\frac{5}{6}$ by 10,000. Thus may be calculated, by the expansion of the air, the force of the current; and hence it follows that the ascent of the heated air in a conduit depends upon its diminution of specific gravity.

Montgolfier was the first who proposed a rule with regard to two columns of air of equal heights, the one heated, and the other of the external air, namely—



Let A B represent a shaft or pit which the air is to descend; C D the upcast shaft, in which the air is to ascend; and F a furnace near the bottom of the shaft C D. The effect of the furnace is the difference—making allowance for the smoke, $\frac{1}{20}$th part—between the densities of the two columns A B and C D. Let D E be the increase of height of the column of air C D by the rarefaction of the furnace, the velocity, or force of the current produced by such rarefaction, will be equal to that which a body would acquire in falling through the space E D.

By the law of accelerating forces, bodies descending from a height, by the force of gravity, through the air, fall about 16 feet in the first second of time; 3 times that distance in the second, or $3 \times 16 = 48$ feet; 5 times $16 = 80$ feet in the third second; 7 times $16 = 112$ feet in the fourth second; 9 times $16 = 144$ feet in the fifth second; and in 5 seconds 400 feet—thus regularly increasing according to the number of seconds during which the body has been falling. The rule to ascertain the number of feet which a body falls in a given time, is to square the time, and multiply the square by 16 (the number of feet fallen in the first second), and this will give the total number of feet. Thus in 5 seconds, 5^2 or $25 \times 16 = 400$ feet.

An example may be given of Montgolfier's rule to ascertain the force of the ascensional current in a chimney. If the decimal ·00208 represents the expansion of air by 1° of F., multiply it by the number of degrees to which the temperature is raised, and this product again by the height of the chimney. Thus, for instance, if the height of a chimney or column of air be 100 feet, and the temperature has been raised to 40° F., multiply the 40° by the decimal ·00208, and again by 100, the height of the chimney, which will give 8·32 feet; or 108·32 feet within will balance 100 feet of cold air without, and the velocity of the efflux of the heated column, when pressed by the greater weight of the cold column, will be $8 \sqrt{8{\cdot}32} = 23{\cdot}075$ feet per second.

These rules become useful when practically bringing the action of currents to bear within the range of science. Thus, as the rarefaction and height are increased, the ascensional force or upward movement is accelerated. This is an important element when directing the agency of heat to the expulsion of impure air.

Although it is therefore established by experiment, that the higher a chimney and the hotter the fire the more rapid is the upward current, or what is termed the draught, still it is important that at the point of efflux of the air from the chimney, it should have sufficient increase of temperature to pass freely into the atmosphere. It may be aided in its exit from lateral pressure, or deflection of the wind by means of turncaps. As the air is cooled in the chimney in the ratio of its distance from the fire, the strength of the fire must be proportioned to the height and area of the flue, otherwise a very high chimney might be less effective than one of a moderate height, because the hot air ascending a certain distance might be cooled down, and the column within become nearly of the same weight as an equal column outside; the effect of which would be that there would be little or no upward movement. It, however, may be taken as a principle fully established, that the ascensional force of the current is the difference between the weight of the column of air heated within a chimney, shaft, flue, stalk, or funnel, and a column of the surrounding atmosphere of equal height and base; and hence it follows that adding to the horizontal length of a chimney or flue will not increase, but rather diminish the current by cooling the air before it reaches the point of efflux. With a knowledge of these simple facts, with how much greater interest will the blue smoke be observed rising, when calm, from the chimney tops at different heights and at different rates of velocity, and curling upwards into the pure atmosphere above, whilst the movement goes on by the established law—namely, that of the respective weights of warm and cold air. But when keeping this law in view, great allowance must be made for friction, bends, the force of the wind, and other impeding causes in flues, before the ascensional force can be duly estimated. To increase the draught without loss of heat and waste of fuel is an important consideration. This may be attained by making all the air in the chimney or flue pass through or near the burning fuel. Supposing the chimney used for carrying off the vitiated air from an apartment, it will be apparent that the higher the temperature at which the air enters, and can be maintained in the ventilating shaft, the greater will be the extractive power.

By attention to these general principles upon which the motion of the air is carried on, the utility or inutility of many of the schemes proposed for ventilation will more easily be judged.

COMPOSITION OF ATMOSPHERIC AIR.

Another important point for the due understanding of this subject is the consideration of the properties of pure air, and their effects upon the human frame. Chemistry and natural philosophy have thrown much light upon sanitary laws. The knowledge of the constituent properties of atmospheric air and its influence upon man, and all organic matter, by improved means of education, is now no longer confined to the man of science, but has become general. An old writer well remarks, "that as every thing that is proper for recruiting the decay of the solid or fluid parts of our bodies deserves the name of food, the air ought to be looked upon as real food, and that which is most necessary for us." Air, therefore, being justly considered in the same light as food, its purity becomes essential to the health of all animals; and as respects ventilation, the amount of supply and the constant renewal of it in domestic dwellings, etc., must be regarded as a primary point for the preservation of bodily health.

It may be useful to keep in recollection a few points connected with that invisible compound fluid, the atmospheric air which surrounds us. This fluid has a general pressure (subject to slight variations as indicated by the barometer) equal to 15 ℔ weight on the square inch at the level of the sea. It is composed of oxygen, nitrogen, and a small portion of carbonic acid and carbonic oxide gases, and a portion of vapour of water. There are in every hundred volumes of atmospheric air, 21 volumes of oxygen and 79 of nitrogen, or in every hundred parts, estimated by weight, 23 of oxygen and 77 of nitrogen. The carbonic acid gas in the atmosphere is usually taken at one part in a thousand. But as the result of a series of experiments, it may be assumed that normal air contains four parts of carbonic acid in 10,000 parts by volume. In thickly populated towns, where the products of combustion are evolved in proportionally large quantities, the per centage of carbonic acid is in general larger than in the open country.* Near the surface of the earth the proportion of it is greater in summer than in winter, and during the night than during the day; also it is greater in elevated situations than in plains. Dalton first pointed out the reason of the equable mixture of the gases in the atmosphere, and why they remain fixed; the principle is, that the particles of elastic fluids are not mutually elastic to each other.

It is important, as regards ventilation, to keep in view the relative specific gravities of these fluids;

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* Par. Rep. 1857.

—oxygen gas is about 750 times lighter than water, and is rather heavier than atmospheric air; its specific gravity being 1·106, that of air being 1·000. Nitrogen gas, formerly called azote, has a specific gravity of ·972, and is thus lighter than atmospheric air. It destroys animal life—no animal can live in it alone. Neither can oxygen alone support life.

It is a remarkable fact, deduced from careful experiments, that the proportions of these gases in the atmosphere are always nearly the same, or about 1 to 4, whether at the level of the sea or upon the tops of the highest mountains, and in every parallel of latitude and longitude. Carbonic acid gas has a specific gravity of 1·524, air being 1000. It forms, we see, but a small portion of the atmospheric air in a state of purity: but it destroys animal life; for an animal immersed in it speedily dies. Its baneful influence requires to be constantly guarded against in domestic dwellings. It is rapidly formed by the respiration of animals, and is evolved in greater quantities in exertion than repose—a man may be held when sleeping to give off one-third less than when waking. It is necessarily produced in the process of combustion.* It will not support flame —it is easily detected by tests—it readily combines with alkalis, forming salts, called carbonates—it is rapidly absorbed by water—at a mean temperature it absorbs its own volume. By adding carbonic acid to lime water, carbonate of lime is formed. And, by exposing pure lime, or barytic, water to the air, in the interior or exterior atmosphere, the presence of carbonic acid is quickly detected; it first produces milkiness, and when in excess solid matter is deposited.

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* Par. Rep. 1857.

The baneful influence of this gas upon the human frame is very great, and probably some persons are more susceptible of its action than others. Dr. Carpenter states, that when carbonic acid gas is increased from the usual proportions of it always in the atmosphere, its injurious effects begin to be felt by man in headach, languor, and general oppression. It prevents the due excretion by the lungs, and it exercises a very depressing influence on the action of the various organs of the body, particularly the nervous system.

As already stated, carbonic acid and carbonic oxide act as poisons upon the animal organism. Both produce asphyxia when inhaled in large quantities; but the amount of carbonic oxide which renders an atmosphere unfit for the support of life, is much smaller than is the case with carbonic acid. Air containing one per cent of carbonic oxide is immediately fatal to animal life, whilst with a per centage of from four to five parts of carbonic acid, respiration can be continued though with difficulty, and life can be supported for a few moments in an atmosphere containing 30 per cent of this gas (Le Blanc). From the different accounts stated by several authorities, it is difficult to come to any definite conclusion. It is, however, generally admitted that air containing more than one per cent of carbonic acid is injurious, and that air containing half a per cent is hurtful if breathed for any length of time.

Numerous authorities assert that a far greater dilution of the carbonic acid is necessary to preserve health (Le Blanc and Peelét). Carbonic oxide is produced by the imperfect combustion of carbon; hence an increased quantity of this gas is found in fuel, with an insufficient supply of oxygen. Carbonic acid, on the other hand, when arising from ignition, is produced by more complete combustion of carbon.*

NATURE OF RESPIRATION.

It has been considered, that the process of respiration is in many respects not unlike that of combustion. The food supplies the carbon, and the oxygen is derived from the air by the act of breathing, while the products are the same as in combustion. Boussingault † remarks, that the carbon and hydrogen of the food disappear, and give rise, by combination with the oxygen of the air, to carbonic acid and water, precisely as if they had been burned. Dr. Carpenter, ‡ Professor Liebig, § and others, assume that the carbon and hydrogen of the system combine with the oxygen taken in from the air in the act of respiration, and serve to produce animal heat by a process resembling ordinary combustion. In this process, from 10 to 12 per cent of the oxygen in the air combine with the carbon in the blood, and produce carbonic acid gas, which, with the nitrogen, is expelled from the lungs at every expiration. On this theory Dr. Carpenter remarks, that the inference seems unavoidable from experiments, that the venous blood, passing through the lungs, gives off carbonic acid and takes in oxygen; or, in other words, the carbonic acid is set free during the act of respiration, and the oxygen is absorbed.

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* Par. Rep. 1857.

† Rural Economy, by J. B. Boussingault.

‡ Animal Physiology. § Animal Chemistry.

According to a series of experiments, the volume of air expired by an average-sized adult man in an ordinary breath may be held to be 30·51 cubic inches (Vierordt), the number of respirations 16 per minute, which gives 480 cubic inches expired per minute, and the quantity of carbonic acid contained in the expired air 4·6 per cent. Hence, the volume of carbonic acid expired per hour would amount to 1·348 cubic inches. This quantity is somewhat larger than that found by Scharling, but the mean, 1·208 cubic inches, may be taken as the highest average of the amount of carbonic acid expired by an adult man per hour.* Some estimate a cubic foot, which contains 1728 cubic inches, as the quantity of air vitiated per minute, and that 10 cubic feet per minute are not more than are necessary to preserve the air in a wholesome condition. Vierordt gives as the minimum quantity of air a man should receive per minute, 2½ cubic feet. Dr. Reid advises 10 cubic feet of air per minute. Dr. Arnott considers 20 cubic feet necessary. The Par. Rep. 1857, states, that to diminish the carbonic acid to a satisfactory minimum limit, probably 20 cubic feet per minute per man is necessary, to remove completely the organic putrescent matter, at least in the case of soldiers' sleeping-rooms. The putrescent matter arising from the animal frame becomes particularly obnoxious when cleanliness of person and clothing is neglected, or from deficient sanitary arrangements.

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* Par. Rep. 1857.

Liebig* calculates that "an adult man, taking moderate exercise, consumes $13\frac{9}{10}$ oz. of carbon in twenty-four hours, which escape through the skin and lungs as carbonic acid gas." "For conversion into carbonic acid gas $13\frac{9}{10}$ oz. of carbon requires 37 oz. of oxygen." Haller estimates the daily loss of weight from the skin and lungs, from 30 ounces in the colder climates of Europe to 60 ounces in the warmer. Lavoisier and Seguin found the human body gives off 1575 grains, or 1·94 cubic feet per hour by the excretory functions of the skin. According to the experiments of Vierordt, the quantity of water exhaled by a man per hour is about 309 grains. Dr. Carpenter states, "that the air which has passed through the lungs contains 1·26 part of carbonic acid; and thus about 17·856 inches (or rather more than 10 cubic feet), containing 2616 grains, or about 5½ oz. of solid carbon, are thrown off in twenty-four hours."

EFFECTS OF IMPURE AIR ON HEALTH.

The air, from the act of respiration, having become deteriorated, before it can be again breathed, must be freely diluted with pure air; and it is certain, taking even the lowest estimate of the air expired from the lungs in the aëration of the blood, when several persons are assembled in a close place the air soon becomes impure, and unless the aerial poison be removed as it is generated, whatever impurities the air contains will be respired and absorbed by the blood; and not only that, but the effete matters are thereby retained. Liebig calculates,* "that an adult man receives into his system daily 32½ oz. (or 46·037 cubic inches) of oxygen, and that the weight of the whole mass of his blood, of which 80 per cent is water, is 24 ℔s." Thus the air inhaled, in proportion to its impurity, may become a slow or rapid poison; and the very aliment which 1 sustains the body will contribute, in close places, to the atmospheric vitiation.

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* Animal Chemistry, p. 13; and also Chemistry, p. 13; by Professor Baron Liebig.

As the entire blood of the body, which is generally estimated about 30 ℔s in weight in a man, passes every three minutes through the air cells of the lungs, consisting of an area of several hundred feet, to be purified by decarbonization in the process of its arterialization, the effect of long inhaling impure air should be apparent. It is no wonder, therefore, that breathing vitiated air becomes manifested upon the human frame. In many employments, where persons are subjected to a close impure atmosphere, its tendency is to bring on premature old age, by gradually undermining the constitution—it injures the digestive organs and depresses the mental faculties; and, by enfeebling the frame, it disposes to consumption and other diseases.

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* Animal Chemistry, p. 12; there appears to be a discrepancy in quantities by different authorities.

The great mortality arising from diseases of the respiratory organs directs attention to how far these may be influenced by impure air. Not that consumption is produced by it alone, but predisposition to that disease, in common with all forms of tubercular affections, is excited by this, amongst other depressing agencies. According to the Report of the Registrar-General of England, 1858, out of the mortality in England and Wales, in 1856, of 390,506 persons, 48,970 died of consumption. In the letter to the Registrar-General on the causes of death, by William Farr, Esq., M.D., F.R.S., it is stated, that consumption is more fatal to women than to men. By this destructive disease, 23,016 males, and 25,954 females died; many of the thousands of deaths may be ascribed, amongst other causes, "to the indoor life of women."[*] The rate of mortality from this fatal disease does not seem to vary very much.[†] In 1849 the deaths from phthisis were 50,209; 1853, 54,918; 1855, 52,290. To this there falls to be added the deaths resulting from other diseases of the respiratory organs, which amounted, in 1856, to 52,908, including 21,528 by bronchitis, and 22,655 by pneumonia. These results show how much care is required to guard the respiratory organs from disease; and as air is the pabulum of life, they instruct, that too much importance cannot be bestowed to inhaling it at all times in purity. From the Report of the Registrar-General of Scotland for

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[*] 19th Rep., p. 195.

[†] 18th Rep., p. 184.

1858, the deaths in eight principal towns amounted to 23,420; 3073 of which were caused by consumption.

The escape of the carbonic acid gas from the lungs, is one of those beautiful contrivances of nature, appertaining to man and animals, by which the design of the Author of creation is brought home to the mind of every thinking and intelligent being, showing how life is momentarily preserved. It has been shown that the carbonic acid gas expired from the lungs is much heavier than common air, as 1520 is to 1000, or half as heavy again. If retained, death must follow; but the heavy air, at its expiration, is combined with vapour, nitrogen gas, and other matter. Dr. Thomson estimates that 6 grains of vapour are exhaled from the lungs per minute. This vapour becomes visible when breathing in the cold external air. Dr. Carpenter estimates the amount of fluid exhaled by the skin and lungs averages from about 3 to 4 lbs. daily. The rarefied air from the lungs thus blended with vapour, is much lighter than common air, and hence ascends with rapidity, even in an atmosphere of a similar temperature. This clearly points out the necessity, as before stated, when applying ventilation to the abodes of men and the lower animals, of removing the carbonic acid gas from above, as it is generated, to prevent the re-inhalation of the air which has been rendered noxious; for unless means are taken for its expulsion, or provision made for its escape when expanded, and if it is permitted to cool before escaping, the carbonic acid gas will, from its greater gravity, descend, and the vitiated air remain.

CAUSES OF ATMOSPHERIC VITIATION.

Although, even in the present advanced state of science, chemical tests can hardly discover any, or a very slight difference in the proportions of the gases in the atmosphere, still the air itself is passing through constant changes. Some local circumstances influencing air can be detected. The insalubrity of confined or ill-aired places is known to every one. A confined lane without an outlet, or a *cul de sac*, may be compared to the stagnant air of a cellar or a well. A current is at all times necessary for the renovation of the air. Effluvia are carried by currents to a great distance. Miasma indicates by its prejudicial effects, atmospheric change or decomposition, or what is noxious to health. The vast amount of oxygen abstracted from the air by the respiration of animals, and in the process of combustion, quickly adulterates the atmospheric air, for the oxygen is converted into carbonic acid gas. The enormous volume of carbonic acid gas resulting from combustion in fire-places and furnaces, and from millions of human beings congregated in large cities, who are constantly giving out carbonic acid from their lungs and skins, must be apparent, and to this must be added, that given out by the lower animals. The quantity of carbonic acid that a horse alone gives out in twenty-four hours has been estimated $79\frac{1}{10}$ oz.*

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* Liebig's "Animal Chemistry," p. 14. According to J. B. Boussingault's "Rural Economy," a cow gives out $70\frac{3}{4}$ oz. of carbon. A pig eight months old, weighing 120 lbs., gives out daily

The nitrogen returns to the atmosphere, and without the oxygen is unfitted for respiration, but by a beautiful process in nature, the carbonic acid gas is absorbed by plants, which retain the carbon for their nourishment, and return the oxygen to the air. The latter being given out from the leaves or foliage in large volume, yield more oxygen than they even extract from the air. The nitrogen, the specific gravity of which is lighter than air, has been supposed to ascend to the upper regions of the atmosphere, and the pure air to descend towards the earth to replace that which has been deteriorated. Nitrogen is, however, known to combine with hydrogen gas, and to take the form of ammonia, a small portion of which is always present in the atmosphere, and which is supposed to be the source of the nitrogen for plants. The specific gravity of ammoniacal gas is ·590. It is rapidly absorbed by water, which takes up more than one-third its weight of the gas. It is by the operation of these beautiful natural laws of the great Author that the air is kept in a state of purity for the preservation of animated nature. But when we come to the habitations of man, and look to the vitiating causes in constant operation which frustrate the action of these natural laws, it is then that reflection impresses on the mind the necessity of devising and employing artificial means to compensate for their frustration.

21½ oz. of carbon, in the form of carbonic acid. See also "Physiologie Comparée," p. 187, par G. Colin. Paris, 1856. Also W. B. Carpenter's (M.D.) "Animal Physiology."

By the functions of the human frame in the abstraction of the oxygen from the air by respiration, and the exhalation of carbonic acid gas by the excretory functions of the body, and by other noxious causes, such as the combustion of gas in close places, the air is frequently rendered unwholesome. But even the external air may be rendered insalubrious by the congregation of mankind in crowded cities, towns, and villages, and confined localities, and the undue proximity of their houses. Wherever drainage, and sewers, and cess-pools are neglected, and refuse depots are accumulated near the dwellings of men, health must suffer, and the rate of mortality be increased; a poisonous atmosphere is generated in the decay of animal and vegetable matter. The air of large localities must become adulterated from sulphuretted, phosphuretted, and carburetted hydrogen, ammoniacal and other deleterious gases. The poison is inhaled by day and night, and it is not perhaps in the power of those compelled by their mode of livelihood to reside in such places to remove from its prejudicial effects. The liquid manure from houses and stables may be often seen in the stagnant gutter or ditch, polluting the air around, which a little trouble and expense might usefully convey to the disinfecting earth. As thus the air in confined and ill-cleaned localities is vitiated from many causes, and loses its elasticity and bracing effect upon the frame, human intelligence and self-preservation, in such places, should point out the necessity of taking every means possible to diminish, if not to entirely remedy the evil. If the atmosphere around the dwelling be vitiated from impure gases, and the air within the dwelling still more so from neglected ventilation, it is impossible to conceive that health can be preserved.

That combustion is one cause contributing to the vitiation of the air of cities there can be no doubt. The difference of the purity of the air in what are termed manufacturing cities and towns from those of an opposite description, may be easily ascertained; and the evil has increased to such an extent from the generation of smoke and the deposit of soot, that an Act has passed the Legislature compelling all proprietors of works to consume the smoke of their furnaces. This, of course, will remedy the evil to the eye, and render the localities more comfortable to the inhabitants; but it cannot greatly diminish the amount of carbonic acid gas produced in the process of combustion, although it rarefies it and removes the smoke. The effects of combustion are more distinctly visible in mines or in rooms than in the external air. Gas cannot be burned without destroying a certain portion of the oxygen of the air; and even coal fires, when they do not draw properly, will rapidly pollute the air of the room. The average quality of coal-gas gives, on burning, from 80 to 90 per cent of its volume of carbonic acid. Wax, oil, and tallow produce, in combustion, about 200 per cent of their weight of carbonic acid; or by burning 2 ℔ of stearine in 1800 cubic feet of air, the quantity of carbonic acid formed will amount to 4 per cent of the total volume, or the acid will have become as impure as if it had all passed through the lungs.*

NEGLECT OF VENTILATION.

The evil effects arising from the neglect of ventilation require no exaggerated picture to be drawn of them. These may be seen in many of the abodes of men. Allusion has been made to the evils resulting in cities from uncleanliness and neglected drainage; but the position of cities, towns, and villages has never perhaps received sufficient consideration, because such places have arisen from convenience, and sprung gradually into importance from accidental causes. It cannot generally otherwise be accounted for that these are often placed in marshy, fenny, and unhealthy districts, and where it is known causes prejudicial to health exist. But it is the province of the few, not the many, to be able to choose the locality of their dwelling-place, and hence it is the more important for those who have the power, to see that everything is done which can be effected in such places to improve salubrity. Dwellings should not be densely packed together, as may be seen in cities built before the period that the influence of air and light were properly known upon the human frame; for the influence of light is essential for the preservation of health. Dark, dirty, confined alleys may be seen in many cities and towns, into which the sun's rays can hardly penetrate, and little pure air find its way. How many an artizan, with his family, there passes his existence! He perhaps has no means of removing from his abode, and if he did so, he probably would remove to one no better. It would be well if such confined tenements—the abodes of hundreds—where disease and sickness so often prevail, could be improved in all cities. Many thousands of pounds annually are spent in much less useful objects. But even the humble residenter in such abodes should be made to know that no air can be so impure without his house as his family must render the air within it. It has been shown that the carbonic acid gas in the atmosphere forms a very small portion of it, and even tried by test from the outside of the window of his obscure abode, it will show a very different result from the air within it. But the air within the houses of the wealthy has no exemption from impurities. It should be again remembered that what has been described as the meaning of ventilation is the supplying fresh air at all times to the dwelling or other place requiring it, and removing that which has been rendered noxious; and that this can only be attained in close places by a slow movement or slight current of air being maintained. But how often is it seen that a mere pane of glass separates the most impure from fresh air. As the air is an invisible fluid, its impurities are not always recognised, and people will sometimes be content, or perhaps obliged, to breathe air relatively as impure as water taken from a stagnant pond. If the eye and taste abhor the water, an equal disgust should arise to inhale the air. Still so potent is habit, that the human frame, in many instances, though suffering a gradual deterioration, gives little immediate notice of what is going on, by causing present feelings of inconvenience, if the impurities be not extreme, and especially if the person be used to it; hence a great source of evil, and the difficulty in arousing proper attention to the whole subject. If an ill-aired house could, as a matter of fashion, be rendered as unpopular as a dirty one, or as having the person or dress impure, the whole battle would be nearly gained; for the chief difficulty is to convince people of its necessity—habits being often formed without reflection. The difficulty of arousing from indifference and inattention to the subject in many instances is extreme.

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* Par. Rep. 1857.

Were people generally impressed with a knowledge of the simple facts enunciated, and were they to try to maintain pure air for the purposes of respiration, and justly view it as important as the food they eat, they would be mindful that without it good health could not be enjoyed. Were parents or heads of families, mothers in the nursery, clergymen, teachers, masters and foremen having people under their charge, were clerks and servants and workmen, impressed with these truths, how different might be the attention paid to this subject, and how much more beneficial the results as regards the health of the community!

Much might be done in the dwellings of artizans, to carry out a systematic mode of ventilation upon a large scale. In the attempts which have been made with this view, as yet few have in any degree been successful. This arises from almost obvious causes, amongst others, that offensive currents have been made from air openings improperly placed at the ceilings of rooms or roofs of buildings, sometimes pouring down cold air like a shower upon the heads of the inmates, chilling all within its range. At other times a strong current the opposite way has been created, equally annoying to the inmates, which leads to the apertures being closed up; and occasionally what is called a ventilator is made so small as to tend only to mislead those who trust to its use. These errors proceed in general from the desire to forward some favourite scheme or theory, rather than seemingly from the wish to obtain the great object in view—the preservation of public health.

AMOUNT OF FRESH AIR REQUIRED.

When alluding to the dwellings of artizans, the cottages of the humbler classes should not be overlooked. How freely is money sometimes expended in the erection of stables, cow-houses, pig-styes, and dog-kennels, while perhaps the health, comfort, and happiness of intelligent beings are too often neglected to such an extent, that whole families, each consisting of six or seven inmates, are huddled together in a single apartment of it may be 14 feet square, and 6 to 8 feet high; the whole space containing less than 1568 cubic feet. Professional men when visiting, in the discharge of their duty, these humble abodes, complain of the injury they suffer in health from even the short stay they make, when inhaling the stagnant atmosphere. In the Report on the

Sanitary Condition of the Labouring Class of the Population, by Mr. Chadwick, many striking examples are given of the evil results arising from over-crowding. The rooms of the labouring classes are described to be dark and unwholesome; floors of clay; the windows frequently do not open—and many of these windows are not larger than 20 by 16 inches—and into a shed of 30 feet by 16 are often crowded, eight, ten, or even twelve persons, the only ventilation being by the door, of which there is but one for two families to enter by; the partitions being merely formed by the backs of the beds or wooden boxes: as there is little fuel to maintain warmth, the doors are kept shut; chimneys are badly constructed; the houses full of smoke; the height of an apartment hardly admitted a person to stand upright, and one contained three small beds, two persons sleeping in each.

According to the estimate of Dr. Carpenter,* a man produces, in twenty-four hours, about 10 cubic feet of carbonic acid.† If he were inclosed in a space containing 1000 cubic feet of air (such as would exist in a room 10 feet square and 10 feet high), he would in twenty-four hours communicate to its atmosphere from the lungs as much as 1 part in 100 of carbonic acid, provided that no interchange takes place between the air within and the air outside the chamber. The amount would be farther increased by the carbonic acid thrown off by the skin. In practice, such an occurrence is seldom likely to take place, since in no chamber that is ever constructed, except for the sake of experiment, are the fittings so close as to prevent a certain interchange of the contained air with that in the outside. But the same injurious effect is often produced by the collection of a large number of persons, for a shorter time, in a room insufficiently provided with the means of ventilation. It is evident, that if twelve persons were to occupy such a chamber for two hours, they would produce the same effect with that occasioned by one person in twenty-four hours. Suppose 1200 persons to remain in a church or assembly room for two hours, they would produce 1000 cubic feet of carbonic acid in the time. Let the dimensions be taken at 80 feet long, 50 broad, and 25 high, the cubical contents being 100,000 cubic feet. Thus an amount of carbonic acid equal to 1000th part of the whole, will be communicated to the air of such a building in the space of two hours, by the presence of 1200 people, if no provision is made for ventilating it. And the quantity will be greatly increased, and the injurious effects will be proportionately greater, if there is an additional consumption of oxygen produced by the burning of gas-lights, lamps, or candles. Hence, says Dr. Carpenter, the great importance of free ventilation, wherever large assemblages of persons are collected together, even in buildings that seem quite adequate in point of size to receive them, and much of the weariness which is experienced after attendance on crowded assemblies of any kind, may be traced to this cause. In schools, factories, or other places, where a large number of persons remain during a considerable proportion of the twenty-four hours, it is impossible to give too much attention to the subject of ventilation; and, as the smaller the room, the larger will be the proportion of carbonic acid its atmosphere will contain after a certain number of persons have been breathing in it for a given time. It is necessary to take the greatest precaution, when several persons are collected in these narrow dwellings in which many are compelled to reside. Even the want of food, of clothing, and of fuel, are less fertile sources of disease than insufficient ventilation, which favours the spread of contagious diseases, by keeping in the poison, and thus concentrating it upon those who expose themselves to its influence.* From recent sanitary reports, it is considered that the cubical space requisite for each person in a house, to maintain a healthy existence, should not be less than 600 feet.

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* Animal Physiology, p. 262.

† The difference of opinion or uncertainty as to the amount of carbonic acid has been shown.

If it be assumed that a man exhales 0·686 cubic feet of carbonic acid per hour, 16 men will exhale 65·86 cubic feet in six hours. "To know what quantity of air must be mixed with 65·86 carbonic acid, so that the percentage of the gas amount to 0·1242, or the quality or the quantity found in the Wellington barrack-room," † . . . "there is required 76·600 cubic feet of air." That is, in six hours 76·600 cubic feet of air pass through the room and carry off 0·1242 per cent of that bulk of carbonic acid. This gives to each man a volume of 13·3 cubic feet per minute—a quantity insufficient to remove completely all animal effluvia. But the amount of ventilation required in a room of a given size occupied by a given number of persons, must naturally partly depend upon the duration of the occupation.

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* Animal Physiology, p. 263.

† Par. Rep., 1857.

Practical difficulties exist in winter in obtaining a sufficient diffusion of fresh air to make small abodes salubrious—local currents are complained of, and prove offensive, hence almost every aperture is shut up; even the fire-place, such as it is, does not draw properly; and the fœtid atmosphere within forms a striking contrast to the pure air without. It is high time, however, that more should be done for the interior comfort of abodes—the external appearance of the cottage, in rural districts, is made to harmonize with the landscape; but much more important is the internal comfort—an effective system of diffusion of the air should be provided, also proper altitude given to the rooms; and the windows and fire-places constructed on the best principle, to insure a renovation of the air of the house at all times.

MOVEMENTS INDUCED BY HEAT.

Although the subject of ventilation is a difficult, it is still a practicable one. It is absurd to suppose that it can be altogether obtained by spontaneous means. Before describing mechanical agents and other artificial means which have been applied to domestic ventilation, some notice will be taken of schemes proposed as a substitute. From the many contrivances called "ventilators," which from time to time have been brought before the public for this purpose, it is impossible to do more in a popular work than mention a few of the prominent ones. Before noticing these, even at the risk of repetition, it is necessary to have a clear conception of what has been called simple, self-acting, spontaneous, or natural ventilation, when applied to domestic buildings. In houses this may be obtained, to a considerable extent, by attention to the before-noticed movement of the particles of the air, which ascend, as the particles of water do in the process of ebulition. A current may, in ordinary circumstances of the atmosphere, be induced from taking advantage of the slight differences of temperature. No error, however, is so common as the supposition, that if air be admitted by a door or window into an apartment, the ventilation is complete, forgetting that air, like other fluids, can do no more than fill a given space, as liquid does a bottle, and that fresh air cannot be admitted to change the air of the apartment, unless means are provided for the escape of that for which it is to be substituted, and this can alone be done, by the weight or specific gravity of the air producing the movement of its particles, and thereby expelling it; the cold air pressing in to restore the equilibrium. But admitting this common error, it is necessary to guard against regarding such an opening as of no benefit. Although the air in a close place cannot be changed without a current, still human life may, in a confined space, be preserved by a small aperture, as an open pane of glass, because even with one opening, the difference of temperature will create a current, as may be observed from the cold air rushing in at the bottom of the door of a close room, and the warm air escaping at the top of it. This movement will go on, without absolutely changing the entire air of the room, until the temperature outside and inside is the same, or till the relative weights are balanced, and the equilibrium is established.

FATAL EFFECTS OF INHALING BAD AIR.

The many melancholy instances recorded of death in confined places, as in ship cabins, by carbonic acid gas arising from charcoal fires, might have been prevented, if attention had only been paid to the admission of a little external air. Dr. N. Arnott* gives the following data to judge how long life would be preserved in a confined place. Suppose a room to be a cube of 12 feet containing 1728 cubic feet of air, there is, without any ventilation, an allowance of two feet per minute for 14 hours. In what a state with such a prospect would a person be placed. The same author mentions, as an instance of the ignorance which prevails as to the evil effects of breathing impure air, the fact of the Buckinghamshire work-girls keeping themselves warm in a small confined room from their own breath: their pale faces and broken health soon told the tale. The same authority, in his evidence before a Parliamentary committee, in 1849, states, that "if human breath accumulate in a place, so as to be about 1 in 15 of the air present, it begins to be hurtful to persons breathing it again, as shown in the pale countenances and impaired health of those who are much in the house, and usually breathe confined air; and if the proportion of breath to air increase much more, the persons die at once of suffocation, as happened lately to ninety-three persons in a passage boat in the Irish channel. But in all such cases it is possible, by maintaining in the place always the due known proportion of atmospheric air, to render the other admixture, even if it be the poisonous breath of patients labouring under infectious fever, perfectly harmless or inert."

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* Warming and Ventilating, by Niel Arnott, M.D., F.R.S.

When a person is accidentally obliged to sleep, or to continue long in a small chamber, where no provision exists to renovate the air, in order to preserve the salubrity of the place, his first duty is to admit fresh air; much better to sleep with a window partially open, or a broken pane of glass, than to suffer from the soporific exhausting effects arising from mephitic air. But history affords many examples of speedy death, when persons have been crowded into close places, with only one aperture for the ingress of the air. That the air cannot be properly changed without a point of ingress and egress, is well illustrated by the fact generally known, that in an empty pit, well, mine, or vat, the air becomes so deteriorated, from the accumulation of carbonic acid gas, that life cannot be supported. This has been frequently illustrated, from descending incautiously a shaft or pit, where the vitiation of the air is at once shown by the immediate extinction of flame, which takes place in a mixture of four volumes of atmospheric and one volume of carbonic acid: and where flame cannot exist, animal life cannot be maintained.

SALUBRITY OF SITE — TOWN AND COUNTRY.

When a number of people is assembled, the necessity presents itself of finding means, by skilful contrivances, to maintain as much as possible the purity of the air, with due regulation of its temperature, and without annoyance to those congregated together. It has been shown that in ordinary dwellings, by a little attention, ventilation may be maintained and health benefited, and that in what is termed a badly aired locality there may exist perhaps a fresher and purer air without than within the house, even in a well aired one; for nature is so bountiful that the worst air without is often purer in comparison to the exhausted air within. But while this fact must be admitted, it does not follow that the utmost attention should not be paid to the choice of the site of buildings, carefully avoiding localities where causes prejudicial to health are known to exist. Indeed, it must be of vital importance to avoid such localities for the sites of factories, hospitals, prisons, &c., and wherever numbers of workmen are congregated together. It has already been said, that too little attention has been given to placing the abodes of mankind in salubrious situations; for health seems to be promoted by the selection of dry elevated sites with a free circulation of air, and where pure water abounds, while damp, marshy, ill aired places, conjoined with other causes (such as inattention to sanitary measures and cleansing) previously mentioned, prove insalubrious and increase the rate of mortality. The rate of mortality, which differs so much, seems to corroborate these averments. In 1856, the rate of mortality in some counties was low—in Dorsetshire and Lincolnshire, 16 in 1000. In London it was less than 22 in 1000, while in Lancashire it was 25·54 in 1000; and reference has only to be made to the statistical returns of the Registrar-General, public boards, and to the works of C. T. Thackrah, and others, to prove it; and it is still more strikingly developed by reference to agricultural statistics, showing beyond a doubt that locality influences health, and even lessens seemingly the effect of neglected domestic ventilation. The salubrity of the air in the country over cities is clearly manifested; even the deficient ventilation of a cottage is compensated by the open door. Notwithstanding all the exposure to the weather and poor diet of peasants engaged in outdoor employment, they are generally more robust and have a longer average of life than town workers.

The Registrar-General of England and Wales, in his Report for 1858, states—"In the districts comprising the chief towns, in which nearly half the population is living, the people died at the rate of 24, while in the remaining districts, comprising small towns and country parishes, the death-rate was 18 in 1000. This shows in a strong light how much room there is for improvement in our large towns, for it is well known that many fatal agents which may be avoided are at work in the small towns and country parishes."* Out of the mortality, he adds, "67,000 persons perished by causes which, if skilfully attacked, may, it is believed, be either mitigated or removed." "A certain number of lives have been saved by sanitary measures." "We want pure air and pure water about our dwellings, and the refuse which infects the air, and makes it poison man, to be restored directly to the soil." It is satisfactory, from these Reports above referred to, to observe, that a considerable improvement in the average of human life appears to have taken place within the last ten years, which improved sanitary measures, it is to be hoped, will increase. In the Report of the Registrar-General of Scotland for 1858, a comparison made between eight principal towns and eight counties corroborates the English Report, in showing that the rate of mortality is much greater in the towns than in the country. May not the many deaths of the young, in comparison with adults, be materially influenced by the inhalation of impure air, combined with poor diet, rendering them more prone to disease?

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* 19th Report, page 29.

Amongst other causes which add to the insalubrity of London, public attention has been directed to the offensive emanations from the Thames, and to imperfect sewerage; and an extensive plan of sewerage has been adopted to remedy the evil. But other cities and towns suffer from defective sewerage, and in summer from the effluvia which arise from rivers and streams into which common sewers and the liquids from public works are discharged—evils which require correction. Another point of much importance as regards salubrity in cities, especially when situated on a plain, is to guard against obstructions to a free current of air, so as to have the advantage of the prevailing winds to pass through them; for it has been found that when the ends of narrow streets are intersected by the buildings of cross streets, they are more or less insalubrious. Many examples to illustrate this might be given.

EFFECTS OF EMPLOYMENTS ON HEALTH.

Although a considerable difference appears to exist in the longevity of people who live in the country from that of those in towns, still occupations must be taken into account when considering this question, as the rate of mortality is greater in one than another. It is singular the Registrar-General of England and Wales* does not class the farmer as a long liver. "About 6426 English farmers die in a year, and of them many are young; 2605 are under sixty-five years of age." "The germs of insalubrity are scattered about in every village; for the rational laws of health are violated in the cottage and in the farm-house. The dwelling-houses sometimes rest on damp undrained ground; they often lie at the bottom of pit-like depressions of the earth, instead of standing on the sites of the higher grounds, from which the water flows away naturally, and the decaying organic emanations are dispersed and decomposed by the winds. The farm-house is often close to the farm-yard, on a low part of the farm, and is ornamented by buildings, ricks, and trees. In the yard, or near it, the refuse of the house and of all the animals is kept month after month, undergoing fermentation and giving off noxious vapours. Into the pond out of which cattle drink, the ammoniacal liquor falls; and it happens, that if the air is stagnant for some days, and the temperature is high, etc., the farm becomes a scene of suffering."*

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* 19th Report, 1858, page 27.

The miner may be said to live in the country, yet, according to writers on the diseases of workmen, such as Ramazzini, Patissier, Thackrah, and others, it is not a healthy employment. The Registrar-General of England and Wales, in his Report, published 1855, states, "Miners die in undue proportion." Ratcliffe, in his tables, says, "This class of lives shows a very large amount of average sickness." Thackrah, in his work, remarks, that colliers do not generally exceed the age of fifty, though many exceptions may be found.

Colliers suffer much from defective ventilation, increased by the smoke of lamps, and by the fumes of gunpowder in mines in which it is used for blasting. They are liable to pulmonary diseases in mines where the coals produce much dust. The lungs become infiltrated with black matter, which a high medical authority † has shown "resembles, if it is not identical, with coal." The injurious effect upon health resulting to miners of lead, copper, quicksilver, and other minerals, has been noticed by several writers; and also the serious consequences arising in other employments from the inhalation of dust, sand, and deleterious vapours. There are, however, many employments in which injury to health arises less palpably to observation during its progress—such as the effect which the continuous respiration of impure or stagnant air exercises upon the human frame, producing those results already noticed, the tendency of which is to shorten life. Dr. A. Combe, in his "Physiology," remarks, "that there are employments, without any thing being positively injurious, in which scarcely a workman survives his fortieth or fiftieth year." This is a serious consideration. Can the importance of ventilation, and the necessity of breathing pure air be overrated, when it is known that many employments are carried on with injury to health, in a close impure atmosphere? But to rectify these evils, the people themselves must be impressed with the truth, that they must view the air which they breathe like the food they eat, and take all the means in their power to obtain it in purity.

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* 19th Ann. Rep., 1858, p. 27. † Professor Christison, M.D.

REFERENCE TO WORKS BY THE AUTHOR.

As many of the contrivances now to be described have been successfully applied to the ventilation of factories and other buildings, and some of them are noticed in a prize Essay by the writer of this treatise, published in the Transactions of the Royal Scottish Society of Arts, "On the Ventilation and Sanitary Arrangements of Factories,"* and also in another prize essay in the same Transactions, "On the Ventilation of Sailing and Steam Vessels,"† and in other published works by the author—he considers that on these two branches of ventilation it is not necessary for him largely to enter, or to minutely describe the numerous contrivances again which he has already brought before the public, embracing, as these publications do, notices of inventions from the period the subject in this country first received serious consideration. Stable and dairy ventilation has been treated by him in his work, the "Farm Engineer." *

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* Printed in Trans. of the Royal Scot. Soc. of Arts; and in Jameson's Edin. Phil. Journal; and published 1844 by Weale, London.

† Published in same Transactions and Journal, 1842-3.

ATTENTION PAID BY THE ANCIENTS TO VENTILATION.

There seems little doubt that public attention was prominently directed in recent years to ventilation from the prison researches by the great Howard, 1715; also from numerous accidents by explosions in coal mines, and from the mortality in the last century on ship-board. It is, however, interesting, on looking into the pages of history, to observe how much attention was paid by the ancients to salubrity and ventilation in the construction of their buildings. This is shown in the pages of Vitruvius, Pliny, and other ancient authors. Air, light, and situation, were deemed of essential importance as regarded comfort and health by the Romans. Varro, in his De Re Rustica, states, "that the skill of the architect may, in a great measure, guard against bad air; though it is impossible by any art to cure the bad air of an ill-chosen situation." This subject has been treated fully in a paper by the author.†

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* Published by Blackie and Co., London and Edinburgh, 8vo, pp. 272, 1849.

† Printed in Trans. of Arch. Inst. of Scot., 1851, p. 184, entitled, On the Ventilation of Buildings, etc., by the Ancients.

CHAPTER II.

VENTILATION BY SPONTANEOUS ACTION.

PART I.

SIMPLE APPLIANCES.

THE idea of applying artificial agency to aid spontaneous ventilation in renovating the air of a building, seems to be of very great antiquity. The Egyptians made use of the *mulguf*, or wind conductor, for this purpose—an apparatus which is still in use in modern Egypt. It consists of a wooden erection placed on the roof of the building, with an angular top, and its mouth open to catch the prevailing wind, so as to convey the air downwards to the rooms below. The principle of operation of the *mulguf* is the same as that of the common wind-sail used in ships. The latter consists of a large canvas tube, the upper end of which is fastened to the rigging, having its mouth open to catch the breeze, and convey the fresh air into the hold or cabins. In steam-ships these are made of iron, to direct the air into the furnace rooms. In some states of the weather the wind-sail is of little service; hence the many expedients which from time to time have been resorted to for the ventilation of ships. In the author's publication, to which reference has been made, plans and suggestions are given for the better ventilation of sailing and steamships.

MOVEMENT OF THE AIR IN APARTMENTS.

Following up the observations in the first chapter, practical examples will now be given illustrative of the modes of effecting ventilation by means of spontaneous or natural movement of the air,—and in order that the subject may be thoroughly understood, the opinions of other writers on the subject will be adduced.

The first consideration that presents itself when applying the subject practically, is,—are the means available to carry out a system of ventilation?—and the next is, to make the most of those at command.

The movements which take place in the air of apartments in the process of ventilation acting either naturally or artificially, one writer has classed under three heads; but it will be apparent that the nomenclature is more applicable to an artificial than to a natural movement. *First*, ventilation by a *plenum* movement or impulse is so termed when the air is blown into an apartment by the force of the wind or by any mechanical power. *Second*, ventilation by a *vacuum* impulse comprises all cases where the discharge is effected by the pressure of the external atmosphere, or by the exhausting power of machinery. *Third*, ventilation by a mixed movement, is when both the plenum and vacuum movements are employed.

VENTILATION BY MEANS OF DOORS AND WINDOWS.

When applying ventilation to a dwelling-house, it is obvious that doors and windows are the usual means existing by which ventilation is promoted. This may be said to be a truism. Keeping in view the principles which have been pointed out in page 29, the point to consider is, how can these be best applied? It is certain that no one will submit to a cold current of air, if it can be avoided. Hence comes the difficulty, Two ways present themselves:—Should there be two sitting-rooms in use, either to ventilate them alternately, or to endeavour to ventilate them in such a way as to avoid the inconvenience of draughts. Suppose the windows of a room are placed at opposite sides, simple means exist of changing the air by the windows being made to open at top as well as at bottom; and by opening a small portion of the lower part of the windward window, and a small portion of the top of the leeward one, the impure air will be forced out. Adopting the terms before mentioned, a *plenum* impulse through the one, will contribute to the discharge by favouring a *vacuum* impulse at the other. In a similar manner, advantage may be taken of the difference of temperature, by admitting fresh air from the shaded side, and permitting it to escape at the unshaded side of a building. A slow current is thus easily established, and the air will be renewed and the apartments kept in a wholesome condition. It is an advantage, when ventilating in this manner, that the windows be as high as the ceiling of the room, or nearly so, and that they should open at the top, by which means a more speedy renovation is effected. When windows turn on a centre point, or open vertically, they afford a ready mode for regulating the ingress and egress of the air.

The windows of rooms being seldom carried up to the full height of the walls, a stratum of heated impure air must lodge near the ceiling unless there be air openings provided for its escape. In some buildings may be seen as much dead space above as below the window. "On one occasion," it is stated by Dr. Milroy, "I saw a clergyman half stifled by preaching in a pulpit where the windows were unusually low and the pulpit very high; his head was above the level of the tops of the windows, so that the air he breathed was only (the day was very close and sultry) the respired air of the congregation below." *

The plan of ventilation by windows can obviously be adopted with great advantage in factories, workshops, school-rooms, and in other places Should the windows be all on one side, and the doors on any of the other sides of the room, by a partial opening of the door and window a slight movement of the air is established. Should a window have a door opposite to it leading into another apartment in which also there is a window, a simple method exists for ventilating both: It need hardly be stated, that although a renovation of the air is thus readily obtained, still the process is imperfect because it cannot at all times be relied on, from the fact that in winter, in crowded apartments, all draughts are offensive and dangerous.

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* Lancet, p. 530, May 28, 1859,—Gavin Milroy, M.D., F.R.C.P.

But in summer, when ventilation is as much required, and when windows can be freely opened,—the means are in the power of every one to admit fresh air to their sitting or bed-rooms. In winter there is the useful auxiliary for ventilation of the open fire;—but for one half of the year this agency is unavailable.

BED-ROOM VENTILATION.

There cannot be a doubt that the ventilation of bed-rooms has been far too much overlooked. When it is considered that a third part of every day's existence is generally spent in the bed-room, where pure air is most necessary, it is surprising that the importance of a constant supply of fresh air for respiration, as well as the necessity of having the air of the room thoroughly renovated when unoccupied, is often overlooked. A free and continuous circulation of pure air in the bed-room during the night is essential for every one,—the more so where a number of persons sleep in one apartment, as in an hospital, barracks, or in a nursery-room. Persons will sleep much sounder where the air is fresh, and they will rise more invigorated. In general, fires, even in winter, are not much used in bed-rooms except in the houses of the wealthy; hence ventilation is dependent entirely upon the windows.

When taking advantage of doors and windows in rooms, it is equally necessary to consider how staircases of public offices, by means of which numerous apartments communicate, should be supplied with fresh air and the vitiated removed, as the latter, ascending to the higher levels, must render the upper rooms ready receptacles for the impure air;—hence there should be an abundant supply of fresh air admitted below, and a proper escape opened at the top of the stair.

In some towns a common-stair forms the means of access to perhaps six or more houses of several apartments occupied by separate families. Very often there are two houses on each landing,—so that there may be fifty persons living in houses or apartments entering from one stair. And frequently may be seen the windows of closets opening into, and soil-pipes passing down, the common-staircase. The air in such staircases is of course close, and often has a bad odour; and as the houses draw a considerable supply of air from the staircase, the necessity of its being properly ventilated, in order to promote the salubrity of such overcrowded residences, must be apparent.

OPEN FIRE-PLACES.

A good deal has been said about the great advantage of open fire-places for ventilation; but much of this is merely ideal, and is received because it coincides with the prejudice in favour of fire-side comfort. It is, however, only useful in winter, and ventilation is necessary for health all the year round. Besides, ventilation by the open fire is only obtained at a great waste of fuel; for the value of it is just in proportion as the combustion of fuel increases the aërial current. Hence sometimes, when the action is most efficient, the current proves inconvenient and offensive. Being a resource in winter readily at command, it has been by some commended, although it has various disadvantages; for when the upward current ceases, or becomes languid, a downward one may occur, and noxious gases accumulate in the room. "The open fire,"* one writer states, "so much prized in this country from its lively and cheerful appearance, exerts also an agreeable effect upon the animal system, by the light radiated along with the heat which it evolves, and the movement of air which it sustains, as it draws off the air and ventilates the apartment in which it is placed; but in point of economy of fuel or facility of regulation so as to maintain an equal temperature, it is perhaps the least desirable of all kinds of heating apparatus." The same writer further notices as disadvantages—"the attendance which it requires, the dust and ashes which it leaves, and the tendency, when neglected, to produce back-smoke if the circulation be not maintained in proper force." In connection with the same subject he states—"The following points require especial attention in the construction of the common fireplace;—1. It should be provided with an independent supply of air entering in its immediate vicinity; 2. An open fire-place, unless the air enters from the ceiling, often produces little or no ventilation above the level of the chimney-piece, and even then it does not afford the best and purest atmosphere; 3. The air above may be comparatively stagnant, and offensive in the extreme from combustion and the products of respiration, while a fresh current moves along the floor to the fire-place." That the vitiated air arising from the gases and the products of respiration, which ascend to the upper part of a room, are not easily dislodged by the open fire, must be admitted; still, with all its faults, in winter it is congenial to the habits of the people, and tends to assist the purification of apartments. It is, however, not at all an uncommon thing to find its utility as an aid to ventilation frustrated by the chimneys being closed with smoke-boards. In bed-rooms this should never be done: it is like stopping an engine's safety-valve. When it is done to prevent back-smoke, which chiefly arises either from the want of a sufficient supply of fresh air to cause the warmer air to ascend the chimney, or from the air being drawn from it to support the combustion in some other fire-place,—the cause of the back-smoke having been ascertained, the proper remedy ought, if possible, to be applied.

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* Art. *Ventilation*, Enc. Brit., p. 897, 7th Edition.

One great fault often pointed out in the construction of rooms is that they are made too tight. Fresh air is shut out from the houses of the rich as well as of the poor;—for no air can get into the rooms but by the crevices of doors and windows. It presents the idea to the mind that people can live without air; for the inmates of some houses are not satisfied unless the perceptible entrance of air is prevented. In a bed-room which came under observation not only was the fresh air kept out by means of a double door, but every crevice was air-tight, whilst a smoke-board effectually occluded the chimney. Such a room would require to contain as much air as would keep the sleeper alive till morning. It is to be presumed that it was not known by the occupier that a man may be poisoned by the breath from his own lungs. An instance of an opposite kind was lately observed:—a fire was kept burning all night in a confined bedroom without sufficient air to carry on the combustion, and in the morning the room was found to be filled with back-smoke and the fumes of sulphur and carbonic oxide arising from the fuel,—while the sleeper was found to be in a state of stupor, which in a short time might have terminated in asphyxia. Such an apartment is highly dangerous to any one, and those who have the charge of children ought carefully to guard against such mismanagement.

AIR FOR VENTILATION COMBINED WITH OPEN FIRES.

The plan for making use of the open fire to heat an external current of air in order to promote ventilation has been lately revived. The idea was long since carried into practice, and was first proposed by Prince Rupert in 1678, and afterwards improved upon by Cardinal Polignac, who, under the assumed name of "Gauger," published a treatise entitled "La Mechanique du Feu." Dr. Desaguliers made a translation of Gauger's work in 1716, and brought these fire-places before the public. In 1745, Dr. Franklin introduced a fire-place which he called the "Pennsylvanian," in which the descending flue of Prince Rupert was united with Cardinal Polignac's "caliducts." Dr. Franklin complains, that his work having fallen into the hands of European workmen, "his principle was misunderstood, and by pretended improvements the quantity of fresh warm air entering the air-box was prevented." Dr. Franklin admits that the idea of his stove was taken from the experiments of an ingenious Frenchman. In 1768 Franklin wrote to Lord Kames, expressing his opinion upon the improvements of chimnies, and in 1773 he wrote an interesting letter to Dr. Cooper, in which he throws out various useful suggestions for combining heating with ventilation. In 1801, Sir G. Paul brought out his improved "ventilating grate." In 1815, a plan was made public, improving on the preceding, by having angular fire-clay tubes placed behind an iron plate at the back of the common fire, which plate communicated heat to fresh air, from without, admitted into these tubes, the air entering the room at the sides of the chimney-piece. Many other schemes for warming the air before entering the room have been proposed, such as passing it through a hollow back in the fire grate;—and when cottages have been built with hollow walls, making use of the void spaces for ventilation.

"Caliducts," which had fallen into disuse have recently been revived in consequence of the "Report to the General Board of Health by the Commissioners appointed to inquire into the Warming and Ventilation of Dwellings," which "Return" was ordered by the House of Commons to be printed, 25th August 1857. From this Report it appears that a series of experiments was made at the Wellington Barracks, London; and, amongst the plans recommended (p. 95), was "the distribution of warm air into the apartment from hot-air chambers round about the grate."

From the personal examination which the writer has made of these barrack-rooms, the plan adopted was found to consist of an open fire-grate with a cast-iron back, having a casing behind, in which a rarefying box or closed brick chamber is placed to receive heat from the metal back and the smoke pipe of the grate. The fresh air is conveyed to the heating chamber by means of a small flat wooden conduit under the floor, and the air thus partially heated enters each room by an oblong aperture above the fire-place, near to the ceiling. At the side of the fire-place there is a flue ascending from the ceiling, which is much more likely to draw off the warm air than to supply fresh air to the persons beneath. It is expected that this plan of warming the air will enable "in cold weather the direct inlets from the outer air to be closed." These direct inlets—perforations through the walls—are placed near the ceiling, opposite to the fire-place.

The mode of warming the external air behind a grate, although it has been long in use, does not appear to have found much favour with the public. One of the earliest objections against "caliducts" at the back of grates was, that they "burnt the air," which operated for many years against their use. At a later period they were again introduced, but were still complained of from their deteriorating the air. Improvements have since been made, but the great difficulty still exists of heating fresh air in this manner without its imbibing impurities from the fumes of combustion, and there is nothing at these barracks to prevent this result. The air cannot be heated unless a constant fire is kept up, entailing a considerable consumption of fuel; and when the fire burns low during the night, cold air will come in at the same apertures, to the annoyance of persons near them.

As it has been stated on the same authority (Par. Rep.) that it is desirable to have a direct supply of air into every room, and to remove from it an equal amount of spent air "rather than that the air supply were derived from accidental sources, by which arrangement all whistling of windows, pressure upon doors, and cold draughts, will be greatly checked, if if not quite prevented," some of the plans proposed for these purposes will be noticed.

As the effect of an open fire produces a fresh current of air along the floor without removing the impure air collected above, various proposals have been made to draw off these products, and thus render more effective the ventilating power of the fire; but these contrivances very often make no provision for the admission of air into apartments. One of the oldest plans used was a circular tin ventilator with revolving vanes substituted for a pane of glass in the window; but this had very little effect one way or another. Another simple mode of admitting air is placing a zinc plate perforated with small holes in the window of a bed-room or sitting-room. Another plan is to place a ventilator in the upper part of the window of a room, so adjusted by a moveable plate as to allow the escape of the impure heated air, and to prevent the current of cold air entering the room.

TREDGOLD'S VENTILATOR.

The subject was taken up more scientifically by the late T. Tredgold, C. E., who bestowed much attention upon ventilation.* He proposed an inverted siphon with one leg placed in the chimney near the fire, and the other leg having its mouth with a register at the ceiling;—that the air will ascend the warm leg and go up the chimney, and a descending current in the cool leg will convey the impure air from the room.

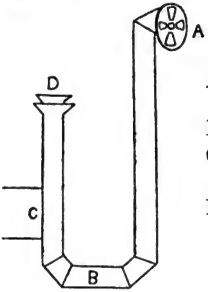

Fig. 2 shows a sectional elevation of this instrument.

A, the register at the mouth of the tube at the ceiling of the room.
B, the lowest part of the curve.
C, the leg going up the chimney, heated by the fire.
D, the mouth of the leg, with an inverted cone to protect the mouth of the tube from falling soot.

A few years ago Dr. Choune of London introduced to public notice his patent siphon ventilator, reviving the same idea. Dr. C. describes his invention as consisting in the application of a principle which he has found to prevail in the atmosphere, of air moving up the longer leg of an inverted siphon, and of entering and descending in the shorter leg, and this without the necessity for the application of artificial heat to the lower leg. He says—" I employ the chimney as the longer leg of the air siphon, which I arrange in order to ventilate a room; and I am enabled to use the chimney, whether for the time being there is or is not a fire lighted in the fire-place of the room, but I prefer, when there is no lighted fire, that the fireplace should be closed."

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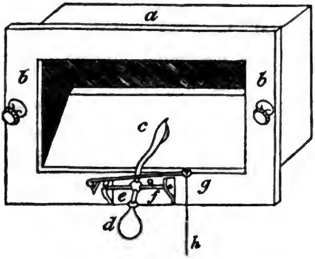
* Tredgold's " Principles of Warming and Vent." 1836, p. 239.

DR. NEILL ARNOTT'S VENTILATOR.

Fig. 3 is a perspective view of the frame and balanced valve.

Fig. 4 is a section of the same, showing the ventilator placed in the wall at the ceiling of the room—the valve opening into the chimney. The same letters refer to both figures.

Fig. 3.

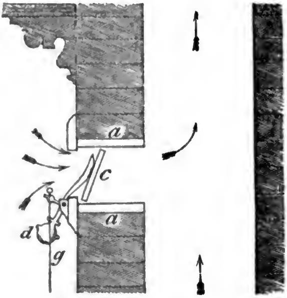


a a, The cast-iron box which is fixed into the wall at the ceiling of the room.

b b, The front frame which carries the valve attached to the box *a*, by means of screws at *b b*.

c, The flap valve which closes the opening.

Fig. 4.



d, The ball which balances the flap.

e f, The axle and its supports on which the valve turns.

g h, A wire attached to the valve, regulated by a screw below, by pulling which the valve is more or less shut but still free to move within the limit left. The valve axle may be lifted out of its bearings.

Dr. Arnott, in a letter addressed to the *Times* in 1849, states that he had recommended to Mr. Joseph Toynbee, the medical officer of St. James's parish, the advantages of having an opening made into a chimney flue through the wall near the ceiling of a room,—and for years he had recommended the adoption of such ventilating chimney passages. Mr. Toynbee, in a locality densely inhabited, had openings made into the chimney flues of rooms near the ceilings by removing a single brick, and placing there a piece of wire gauze with a light curtain or flap hanging against the inside to prevent the issue of smoke in gusty weather. "The effect," says Dr. Arnott, "was so remarkable, that there was an extensive demand for the new appliances, and Mr. Toynbee had soon to report in evidence before the Health of Towns Commission, both the great reduction of the number of sick applying for relief, and of the severity of diseases occurring."

The utility of the plan seems to have been admitted; for the Board of Health, in one of their notifications, which was published in the Gazette in the autumn of 1849 when the cholera was raging, intimate that in badly ventilated houses, "considerable and immediate relief may be given by a plan suggested by Dr. Arnott, of taking a brick out of the wall near the ceiling of the room, so as to open a direct communication between the room and the chimney." With respect to the iron frame and valve known now as Dr. Arnott's ventilator, the Doctor remarks—"I devised a balanced metallic valve to prevent, during the use of fires, the escape of smoke into the room. The advantages of the openings and valves were so soon manifest, that the referees appointed under the Building Act added a clause to their Bill allowing the introduction of the valves and directing how they were to be placed—and they are now in very extensive use."

Although these ventilators are not in every case successful, yet in many instances, when the apertures are properly adjusted and the chimney has sufficient draught, they answer the purpose intended; but their appearance and risk of blackening the walls in fine rooms will always operate against their general application.

The utility of Arnott's ventilator arises in a great measure from its action being spontaneous,—which brings the fact prominently forward, that to make ventilation in private houses really useful, it must act at all times spontaneously. Any call upon attention, even such as the opening of windows, or their regulation in a particular manner, will be apt to be neglected, more especially in places where the inmates cannot at once perceive the reason, or that any apparent advantage is to be derived from the additional trouble required. Even the brick openings before described may be closed up, and balanced valves rendered nugatory.

GLASS VENTILATORS.

Of late years plates of glass have been much used, acting like a venetian blind, which are made to form a pane or panes of glass in a window without interfering with the light, the current of air being easily directed by the plates upwards or downwards. They afford a neat, simple, and convenient mode of admitting fresh air directly into rooms. By the judicious arrangement and management of these ventilators, they may be made to establish an inward and outward currents in a room, without the necessity of opening windows unless a greater supply of air were required. They are, however, liable to the same objection that open windows present,—that when people sit near them they will generally be found closed, because the warmer the room the greater the rush in of cold air to restore the equilibrium. Moore's patent lever ventilator, made of glass, is on the plan now mentioned, with the louvres so arranged as to throw the air upwards or downwards. Some of these glass ventilators are arranged to slide upwards and downwards. Sheringham's ventilator, for the admission of pure air through an external wall, is a simple contrivance consisting of a frame with a regulating valve. It is very much the same as Arnott's ventilator, placed externally.

Another plan of ventilation, but only embracing one point of it, has been lately presented to the public, following up the old custom of having the cottage fire in the middle of the apartment. It is a plan adopted in America for the ventilation of school-rooms. The chimney in the middle of the room, which carries off the smoke from the stove, has a second chimney round it, and the inner chimney heats the air of the outer one, which is tapped at the upper part of the room to allow the heated and impure air to pass into it, and the ascending current thus created in the outer chimney rids the room of the vitiated air.

Another plan, brought forward about ten years ago before the Society of Arts, London, by Mrs. Varley, is deserving of notice under this head. It consists of a perforated zinc tube connected with the external air, and passing round three sides of the room, at the cornice; the fourth side has a corresponding perforated tube on its cornice with its exit into the chimney; this carries off the vitiated air by means of the ascending current of the chimney. It has been stated that this plan has been successfully tried at a schoolroom in London where 200 children assemble.

Various other modes of admitting air have been proposed; but in winter all these schemes generally prove abortive, and are no better than the open window, which in summer is refreshing, but in winter offensive. Let no one be misled as to the efficiency of many of these contrivances, however useful some of them may be in promoting partial ventilation. It must be impressed on the recollection that fresh air cannot altogether change the air of an apartment unless means are provided for the ready and free escape of that which has been vitiated; in other words, the supply and discharge of the air must be regulated by properly proportioned apertures, either natural or artificial.

ROOF ESCAPES.

A few of the contrivances which have been suggested to assist spontaneous ventilation may be noticed, such as the different kinds of ventilators, with or without wind vanes, turncaps (fig. 5), cowls, hoods, or air-escapes (fig. 6), louvres (fig. 7), and ventilating tubes, seen on the tops of buildings. Some of these are useful auxiliaries for the free discharge of the foul air into the atmosphere; but it is not possible by any such arrangement to effect the object of proper ventilation, although it greatly adds to the facility of it. Some very neat designs for Four-point Ventilators have been published by Mr. Muir, Manchester.

Fig. 5.

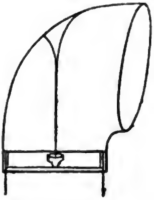


Fig. 6.

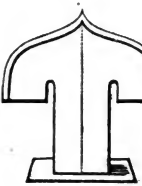
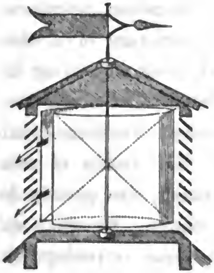


Fig. 7.



Much yet remains to be done to place the ventilation of domestic dwellings beyond the caprice or taste of individuals. It would require to be incorporated in the construction of the building, cheap and self-acting, not liable to get out of order, and requiring no care whatever from the inmates. The wealthier classes do not suffer much, perhaps, in their domiciles from the neglect of ventilation, but many medical authorities * point out the necessity of attention to it in the construction and management of

* Sir James Clark, Dr. Arnott, &c.

houses, and that careful consideration be given to the purity of the air breathed by the inmates; for where ventilation is imperfect the gaseous products are highly pernicious, whether arising from excessive illumination, or from the kitchen, smoky chimneys, or drains. If the pure element is required in the houses of the rich, it is still more required in the dwelling of the artizans and the peasant, as in the latter there are more deteriorating causes in existence to render the air putrescent;—the effluvia from animal and vegetable matter —even the want of personal or domestic cleanliness, contaminate the very walls and furniture of a close apartment. A great deal is said about improving the social position of the working classes; but unless they possess clean, comfortable, well-aired dwellings, little improvement can be expected. The habits of men, and even of generations of mankind, are greatly influenced by the state of their dwellings. Its effect will be to make them sober and industrious, or perhaps the reverse. It has long since been observed that vitiated air greatly increases the tendency to intemperance. Dr. D. B. Reid * says that the evil effects resulting from excess in many cases do not arise from taking more than the constitution requires, but from the vitiated air with which the system is usually surrounded. All rational means should be adopted to improve the dwellings of the labouring classes: if there is discomfort at home, it will drive the inmates to seek comfort else-

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* Reid's Illustrations, p. 180.—Examples are given to show that much more food and drink can be taken in a room which is well aired, than in one which is not. Hence the increase of appetite felt by those taking much out-door exercise.

where. It is in vain to think that any plan of sanitary arrangement, however good—that any plan of ventilation, however perfect, will improve the social position of this class—unless, while you tell them of cleanliness and comfort, you place these two articles within their reach; and surely it is the duty of the civil magistrates in crowded cities to look after the domiciles of the labouring classes. As no efficient system of spontaneous ventilation is likely to be applied without attention, this fact must be impressed on the minds of all classes,—and then any attention required in its operation would not be neglected.

RENOVATION OF AIR IN CLOSE ROOMS.

Reference has been made at page 27 to the amount of fresh air required in order to maintain a healthy atmosphere in close apartments. The opinions which were originally entertained on this subject have varied greatly in recent years. Tredgold considered that about three cubic feet (but the quantity depends on the purpose to which the building is applied) should be changed per minute for each person. Dr. D. B. Reid, whose opinions are deserving of every consideration, states that not less than 10 cubic feet per minute should always be allowed for each person when it is at an equable temperature. This implies that the air in winter should be raised in temperature before its admission; or, in other words, that an artificial atmosphere is to be formed, which is to be purified and regulated in moisture. The Report of the Commissioners referred to at p. 50, recommended that 15 to 20 cubic feet per minute should be allowed for each occupant.* In the same Report, at page 98, it is stated—" As the question of health is one of the very first importance, we have paid very particular attention to the present defective state of barrack accommodation. The space allowed for 16 men in the Wellington Barracks is 33 feet long, 20 feet wide, and 12 feet in height. This gives an area of floor surface equal to 660 square feet, and contains in cubic contents 7,920 cubic feet; each man will therefore have 41·6 square feet of floor, and about 500 cubic feet of space." . . . " Now, it is evident that a man requires, according to the best authorities, at least 10 cubic feet of air per minute, but in close rooms, and in order to retain the atmosphere in a healthy state for respiration, it is found that 20 cubic feet is not too much. This being the case, it will be seen on referring to the experiments in the Appendix, that the quantity of air contained in one of the barrack-rooms will be expended by 16 men in 25 minutes, or it would require the cubical contents of the whole room replenished in that time. Viewing the subject in this light, we find, in the construction of those rooms, that there are no means provided for a supply of air at all equivalent to the consumption that is continually going on during the hours of rest, or when the whole men happen to be in the room for any length of time. Under these circumstances, instead of having a supply of 20 cubic feet of fresh air per man, they cannot by possibility, when the door is shut, have one-fourth of that supply. Living and breathing in such an atmosphere, impregnated with the impurities of putrescent bodies or effluvia proceeding from the lungs of so many persons in a small space, is quite sufficient to account for the unhealthy state of the army, and the consequent injuries which an atmosphere of this kind must eventually and at no distant period, entail upon the health of those subjected to it."

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* Par. Rep. 1857, pp. 94, 130.

The Victoria Hospital for soldiers, recently erected at Netley near Southampton, affords an example of the attention now paid to the necessity of allowing ample space for respiration. The length of this building is 1424 feet, its height 50, and there is a corridor on each floor running the entire length of the building; and from this corridor access is obtained to the various wards and apartments. It is calculated that each man will have allotted to him from 1500 to 1900 cubic feet of space.

PART II.

VARIOUS ILLUSTRATIONS OF VENTILATION.

The appliances for making the most of doors and windows and fire-places have already been pointed out; and in general these are the only modes for ventilating existing buildings. Of late years, however, a system has been adopted of having air-flues or conduits made in new buildings, especially if intended for public purposes; and it is of advantage to have these constructed in such a manner that the volume of air admitted or discharged be placed under control and regulated at pleasure.

AIR ADMITTED, AND REGULATED BY BAROMETRIC PRESSURE.

Dr. Reid considers that the quantity of air to be admitted ought to be regulated by the barometer; "for the amount of air regulated by atmospheric pressure supplied to the blood in the lungs varies at each inspiration according to the density of the atmosphere inspired, from this cause that more air, by more frequent inspirations, may be requisite when the barometer is low, that a proper supply may be obtained." The diminution of pressure, as indicated by the sudden fall of the barometer, is considered by medical men to predispose to some of the maladies to which the human frame is liable; and in some peculiar cases of disease benefit appears to be derived from a change in the density of the atmosphere. A sudden change of pressure produces well known effects upon stagnant ponds, marshes, and drains, and upon the fire-damp of mines, in which a diminished pressure causes the liberation of pent-up gases.

The attention of physiologists seems to have been long directed to the effect which condensed air has upon the human frame. It is well known that the mercury in the tube of a barometer falls as the elevation of position increases, whether by ascent in a balloon or to the top of a mountain, and that this is due to the diminution of atmospheric pressure. Thus the barometer, which indicates 28 inches at the level of the sea, shows only 24 inches at the top of Mount St. Bernard in the Alps; and water, which at the former level boils at 212°, boils in the latter at a much lower point. Thus, by the rarefaction of the air by heat, diminution of pressure ensues and similar results are obtained. So far back as 1677, Dr. Henshaw, F. R. S., proposed a plan to cure diseases by having a chamber so constructed that those within it were subjected to the influence of an air-pump by which the atmosphere could be either condensed and made heavier by forcing air in, or lighter by conveying air out. In recent years Dr. A. Ure has pointed out the influence which air by diminished pressure or rarefaction has upon the animal frame. He mentions that the experiments of M. Junot, of Paris, prove the advantages of compressed over rarefied air. This is corroborated by the sensations experienced at increased altitudes from the more rapid circulation of the blood. The reason why rarefied air is not so salubrious as dense air, is because the latter, in equal bulk, contains more oxygen; and hence more frequent inspirations must be made in rarefied air in order to supply an equal amount of oxygen to the blood.

ARTIFICIAL ATMOSPHERES—OUGHT AIR TO BE PREVIOUSLY WARMED.

This subject is well deserving of attention, especially in regard to places where many persons are congregated. But artificial atmospheres of equable temperature for the general purposes of ventilation are next to unattainable. In spontaneous ventilation, in ordinary circumstances, it becomes a difficult matter even to have the air warmed at all before its admission, and several highly important questions upon this point present themselves for consideration. These are, *first*, whether the air itself is not rendered less rather than more salubrious by its previous rarefaction; *second*, whether it ought to be previously warmed, filtered, moistened, and regulated in temperature, before its admission to a house or building—that is, whether we shall give air and heat combined; or, *third*, whether it is better to have the warming and ventilating processes separated, to raise the temperature of the air of the apartment by means of heat radiating from a moderately heated surface within it, and to keep the ventilating arrangements separated—that is, in other words, to admit fresh air as it exists external to the building. Much may be said upon these heads; but it has been urged with strong reasons, that the air itself is less deteriorated by separating the processes of ventilating and heating. The late Mr. Robertson Buchanan, C. E., who possessed great knowledge and experience, has given his opinion very decidedly in favour of not warming the air previous to its admission, in his work on Heat published some years ago. Thus he says—"It has been proposed by some to heat the external air and throw it into the apartments in a manner similar to some kinds of stoves;—supposing that by thus combining ventilation with heating, it would be more salubrious. But this would be obtaining heat at a very great expense of fuel, and be losing one very important advantage which attends the heating by pipes, viz. that the heating may be kept perfectly separate from the ventilating process, so that each may be managed separately, and no more heat or ventilation given than is required. Whereas, on the other plan, there must always be nearly the same ventilation, whether the external air be dry or damp, warm or cold. When damp, a great quantity of moisture must be thrown into the building, which will require additional heat to suspend it in order to prevent it from being injurious; and when the air is dry, the current of air will carry in dust along with it. I would therefore recommend producing the current from the rarefaction of the air within the building, and ventilating by the window, or some other proper openings for the purpose."

Tredgold seems to have been much of the same opinion, for he says—"Warming the air which is actually in these places, is better than throwing in warm air, for less fuel is required and better ventilation is effected by warming the air, and it is much to be preferred to the plan of drawing air from the basement or area of a house and warming it; for such air is too frequently stagnant and unfit to be introduced into a dwelling-room. Whenever warmed air is to be introduced, it should be brought from a higher level, where it is frequently changed by the winds." *

It has been urged by other writers, that by raising the temperature of the air before admitting it into the rooms, its power of absorbing moisture is increased in a very great degree, and great attention is then required to be paid to the hygrometrical condition of the air, and that it be supplied with moisture to render it wholesome. It has also been urged that the warm air entering the apartment does not readily blend with the air within; from being at such a different temperature, and rising on account of its rarity, it ascends rapidly to the upper part of the room, leaving the lower part of it cold.

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* Tredgold, p. 159, third edition.

MOISTURE A CONSIDERATION IN VENTILATION.

Whether it be admitted that it is better to have the air warmed previous to its entrance into a room, or that it is better that it should be admitted in its natural condition and warmed afterwards from radiating surfaces, one thing must be apparent,—viz. that consideration should be given to the element of moisture in the ventilation of buildings. As the capacity of air for the absorption of moisture increases with its rarefaction and motion, it must exert much influence upon the human frame. That evaporation is rapidly increased by heat, is at once shown by the fact that when a person in damp clothes goes near a fire he feels a chilling coldness, because the air absorbs moisture in a state of vapour, and the vapour requires a great quantity of heat in the latent state for its formation; hence the paradox of a person feeling cold when entering a warm room. Cattarh is thus more likely to be caught in damp than in dry weather. The sensations of heat and cold are often fallacious indications as to the real temperature of the air.

A certain amount of evaporation is essential to health; but when too much moisture is abstracted from the surface of the body, it produces the wearied sensation upon the eyelids, the lassitude and headache, which are experienced in crowded places such as churches, theatres, and ball-rooms. As the elevation of temperature of the atmosphere gives it the power of absorbing a larger quantity of moisture,—in such cases as these, when the natural supply to the air must be impeded, the air entering the lungs and respired at the uniform temperature of 94° will absorb from the mucous membranes of the nostrils, throat, and air-passages, the moisture its temperature requires, thus causing increased action, unpleasant sensations, and tendency to disease. These effects are likewise experienced from harsh, dry, easterly winds;—no matter how high their temperature, they produce these evils from their having a low dew-point and not containing a sufficient quantity of moisture. It is mentioned that in an ascent of Mont Blanc the effect experienced from the increased rarefaction of the air was, that the quantity of moisture lost by respiration was so much increased that the throat became parched and the thirst intolerable—the air itself was as if thirsty, and its extreme dryness deprived the body of its moisture.

Many devices have been employed to detect the presence and amount of aqueous vapour in the atmosphere. The instruments used for this purpose are called hygrometers—contrivances of obvious utility for ascertaining the humidity of the atmosphere, whether in its normal condition, in occupied buildings, or in the green-house. It would be quite out of place in this work to enter upon a description of these instruments, many of which display great ingenuity. The expansion and contraction of hair was employed by Saussure in the construction of hygrometers, and De Luc used whalebone for the same purpose. Professor Daniel's hygrometer, consisting of small glass balls, is well known. Ether is employed to produce evaporation, and to cool one of the balls, until a condensation of atmospheric moisture takes place on its surface. The temperature at which this occurs is called the dew-point. There are many other hygrometers, such as Pouillet's, Hutton's, M. de la Rive's, &c. It must have been known for ages that humid air wets bodies which are colder than itself, "though it has not been long known that dew or hoar-frost affords the most universal example of this all the world over." "The ancients appear to have conjectured that a copious deposition of moisture on cold bodies prognosticated bad weather; but the first step, perhaps, towards applying this principle to the construction of the hygrometer was made by the Florentine Academicians, who having suspended in the open air a conical vessel filled with snow or ice, supposed the humidity of the air to be proportioned to the quantity of moisture, which, being condensed on the exterior surface of the vessel, trickled down its sides and dropped from the apex of the cone. This, however, would afford but a vague estimate of the humidity of the air." "The same idea was further improved upon by M. Leroy of Montpelier, who by dropping ice into water contained in a vessel with a bright exterior surface, gradually lowered its temperature till dew began to be deposited from the contiguous air on that surface. The temperature to which the vessel is thus brought at the moment of incipient deposition, is obviously the temperature to which, if the air were cooled under the same pressure, the vapour in it would be in a state of saturation, or ready to deposit dew upon anything in the least degree colder than itself. Such temperature is therefore denominated the dew-point."*

If there be a great departure from the proper degree of humidity at any temperature, the air in a room will be either too dry or too damp for healthy and agreeable respiration, and more particularly to all the occupants who are in any way subject to pulmonary affections. Dependent on the hygrometrical state of the air, is the amount of vapour carried off from the lungs at every respiration, and that which is exhaled from the skin. With a low dew-point, and a high temperature of the air, a large quantity of vapour is carried off from the lungs, and but little exhaled from the skin; with a high dew-point the air will be a much less powerful absorbent of moisture, and will therefore absorb less from the lungs, while the exudations from the body will be greatly increased. Excessive heat, moisture, or dryness of the air, destroys its salubrity and acts injuriously upon the animal system. The general temperature of the air of an inhabited room differs little with the season, and is usually at about 60° in winter and 65° in summer. When the watery vapour exceeds 80 per cent. of the total possible quantity of moisture which the air can retain, evaporation from the lungs and the skin is checked; when it is below 50 per cent. the exchange proceeds too rapidly, and unpleasant sensations of dryness are experienced.*

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* Encyc. Brit., Vol. xii., p. 120, 7th Ed.

The amount of water necessary to render it healthy and agreeable at these temperatures may be inferred from the following considerations.—The quantity of moisture dissolved in the air when fully saturated will vary as the temperature.—"Air between the temperatures of 30° and 70° has its capacity for moisture doubled for an increase of less than 20° of temperature;—at 30°, when saturated with moisture, it contains 2 grains to a cubic foot; at 41° it contains 3 grains; at 49° it contains 4 grains; at 56°, 5 grains; at 66°, 6 grains; and at 70°, 7 grains. When, therefore, the air of a room is heated sufficiently at times when the external atmosphere is at a low temperature and consequently contains very little moisture in the invisible state of vapour, the air becomes very dry, and this extreme aridity causes a rapid absorption from the skin and lungs of the occupants of the room; the loss of heat caused by this rapid evaporation contracts the blood-vessels at the surface, whilst others not exposed to its influence are surcharged with the fluids driven from the extremities."

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* Par. Rep. 1857.

It is therefore absolutely necessary that water be present in the air to the amount of little less than 3 grains at 50°, 4 grains nearly at 60°, and to more than 5 grains at 70°, in every cubic foot of air. These amounts of moisture will be present when the wet-bulb thermometer reads about 45°, 54°, and 63°, respectively; when the dry-bulb reads 50°, 60°, and 70°, giving dew-points of 40°, 49°, and 58°, successively, or a degree of humidity about 60 when complete saturation is represented by 100.

If the air in a room cannot escape freely, it will absorb the vapour given off from the skin and lungs, and the additional humidity imparted to the air will cause an increase in the degree of moisture, supposing the temperature in the room to remain unchanged; the air becoming too damp is one of the evils of defective ventilation. This is seen when the walls of a crowded room run down with moisture, indicating that the air is saturated; and condensation of vapour takes place from the walls being colder than the surrounding atmosphere. This aqueous vapour deposited on the walls is chiefly evolved from the lungs and skin, combined with carbonic acid gas. It impregnates both the walls and the furniture with sickening effluvia, and on account of its levity, it, in the first instance, ascends. The air may thus become too moist as well as too dry, and both extremes are injurious to health. Thus may noxious effluvia and miasmata be re-absorbed into the system and conveyed into the blood. A stagnant, moist atmosphere thus becomes by absorption a poisonous one. The truth of these statements is illustrated in nature by the effects produced in different localities and climates. In an evaporating air the atmosphere is clear and dry, and if not too dry is more salubrious than when the air is saturated with moisture; for when it reaches the dew-point evaporation ceases and absorption takes place. It is shown by the experiments of Dalton that evaporation is increased by the motion of the air. He found that the evaporation from a cubic foot of water in calm weather is only 22½ grains, while in a moderate breeze it is 29 grains, and in a high wind 35½ grains. The effect of being long confined in air saturated with moisture may be observed in those manufacturing employments where the air is constantly impregnated with the vapour arising from steam or hot water, in producing disease of the glandular system of the human frame; and it is well known that when people live in damp under-ground houses or cellars, they suffer in health from it.

THE DRYING EFFECT OF DIFFERENT HEATING SURFACES.

From the preceding observations it will be apparent that it is the degree of temperature to which the air is raised that produces its drying or evaporative action ;—hence in producing an artificial atmosphere in apartments, the degree of moisture to be imparted to it should be in exact proportion to the degree of temperature of the air in the apartment; for the air may be rendered so dry and greedy in its action, or what is termed its capacity for moisture may be so increased, as to render it unfit "for the healthy respiration of human beings or of plants." This being generally known and admitted, the author finds it stated in one Scientific Journal,* that "it is not of the smallest importance how the increased temperature to the air is given—whether by an air-stove, or by an open fire-place, or by steam or hot water pipes; the drying effect is exactly the same, and exactly proportioned to the degree of temperature to which the air of the apartment is raised."

Surely there is another element which comes into action in the effect of these different heating media, though the drying effect may be the same, which may render them more or less injurious. It is a well-known and admitted fact that the atmospheric air in contact with heated surfaces of iron undergoes two chemical changes: —First, at a black heat of about 300° Fahr., a partial decomposition commences, by the burning or scorching of the dust mixed with the atmospheric air (visible in the sunbeam), which is chiefly composed of animal or vegetable matter;—in the second stage, or when the iron reaches a red heat (often visible in stoves, even in day-light), say 700° of Fahrenheit, complete decomposition takes place; the oxygen is rapidly consumed, forming an oxide on the surface of the metal, and the vapours are converted into hydrogen or carburetted hydrogen gas. The rarefied air which passes from the stove must be chiefly composed of nitrogen, and the effluvia arise from the burning of the floating matter. As hydrogen is of itself inodorous, the smell is more likely to be produced by the carburetted hydrogen disengaged by passing over the heated iron surface, or by the decomposition of animal matter. To inhale such air even for a short time must be highly injurious to the human frame. The effect, however, is not generally perceptible, and it is in some measure modified by the rarefaction of the air, which partially retains it at the upper part of the apartment, while the increased capacity for moisture causes the warm air to receive more rapidly back its oxygen, and remixes it with atmospheric air. It is incorrect to say that the effect of all heating agents is alike. The combustion of coal gas will dry the air, but in doing so it injures its purity by consuming the oxygen and producing carbonic acid gas. In the preparation of artificial atmospheres, stoves are unquestionably the most pernicious in imparting drying properties to the air, and hot water is preferable to steam-pipes * or gas heat.

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* Trans. Royal Soc. of Arts, 1859, p. 89.

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* By an ingenious arrangement Mr. A. W. Perkins of London modifies the temperature of his patient hot-water pipes to any degree, by passing the flow-pipes from the furnace through tanks of cold water.

POINTS FROM WHICH AIR SHOULD BE TAKEN.

Another subject deserving of consideration when making ventilating arrangements is to take advantage of the prevailing winds, and to admit fresh air into buildings by means either of conduits or flues only. This point has long engaged the attention of scientific men, but as regards general ventilation it is a question more dependent on local circumstances than on theory. Whenever the air at a low level is loaded with moisture and noxious exhalations, it should be avoided. Dr. D. B. Reid and others, in order to get rid of this risk, and to obtain the purest air, propose rather to take the fresh air from the highest altitude, but avoiding chimneys.

To show the length to which this subject may be carried, it may be stated that Dr. Reid proposes that extensive public erections be made in towns, to draw down a comparatively wholesome atmosphere from the height of 200 or 300 feet—an object, he says, of considerable importance. In large towns like London and Manchester, where local impurities abound, special means may be adopted that are likely to be most effectual. He further suggests that filter beds should be constructed, so that the air may be filtered through any porous texture to exclude suspended soot. It may be washed with water, particularly lime-water, to fix sulphurous acid and other gases, and admitted at the lower part of the building. These schemes, although gigantic, deserve due consideration, especially in large manufacturing cities, where the air is charged with impurities. These views are in some degree supported in the Report of the evidence taken by a Committee of the House of Commons in 1835 on the ventilation of the Houses of Parliament,—the summary of which was, that the atmospheric air should be received into a chamber of preparation at the basement, from a locality where the air was entirely free from damp or smells of any kind, and be taken from a higher rather than a lower level;—that the ventilation should be so arranged that it could be combined with or separated from the warming chamber,—and that it should continually operate, and constantly afford a pure wholesome atmosphere pervading the house, breathing into and flowing through it, and that the inlets and outlets should be under efficient control.

These opinions, resulting from the evidence of scientific men, would be of very great importance if they could be acted on. It is obvious, however, that even if carried into effect, there are very few buildings in the kingdom to which they are applicable; yet although it may not be possible to adopt the whole, such suggestions may be taken advantage of as seem expedient in the circumstances of the particular building. It is also obvious that these suggestions are more adapted for apartments or houses in which there are many occupants, than for houses in open localities where there is at all times an abundant supply of fresh air.

Although the Report just referred to was specially directed to the Houses of Parliament, yet a few years have brought about many changes both in the plan of ventilating and heating them, as will afterwards be noticed. So far as regards private houses they are almost nugatory, as they involve a system of artificial ventilation, whereas for these the object generally sought is to accomplish most readily ventilation by spontaneous methods. It is necessary, therefore, to fall back upon what are considered the simple elements of ventilation. The next step beyond the window system is merely an extension of it. It is to provide openings at different levels in the apartment, and to cause cold air to come in at the lower aperture, and to permit the hot corrupted air to escape at another opening at or near the ceiling. This is the general idea,—and no doubt, when the apertures are properly arranged, spontaneous ventilation may in some degree be obtained. But in an instance which lately occurred, where a tube was led from near the ceiling of a school-room to the outside of the wall, the constructer was surprised when he found the cold air rush in, instead of the impure warm air going out. He had overlooked the fact that no provision had been made for the inlet of air below, and the room being warmer within, the cold air rushed in as before explained, to restore the equilibrium.

ASCENDING MOVEMENT OF THE AIR CONSIDERED.

As some difference of opinion exists as to whether the fresh air should enter the apartment from below and the impure air escape from above—which is the natural law—a few opinions of scientific men may usefully be adduced to corroborate the author's views on this point; but it will be more fully illustrated in another chapter, in which some of the buildings are described where a downward circulation of the air has deen adopted.

Tredgold remarks (page 73) that "the heavy gas (carbonic acid) will be so mixed with azotic gas and vapour, both of which are lighter than air, that the combination must ascend and occupy the upper part of the room, and will cool and mix with the air of the room if not allowed to escape, while its increased temperature gives it the proper degree of levity. Hence the ceiling of an apartment is the proper place for the outlet and the form of the ceiling may be such as will facilitate the ascent of the vitiated air to the outlet! . . . . The spaces for admitting fresh air should be near the floor, and should be required nearly of the same size."

Dr. D. B. Reid observes—"As a general rule, vitiated air collects above in any apartment more than below," and that "an ascending movement should be given accordingly to the air which enters, so that when it has once come into contact with the system it may be propelled onwards, and never return again to the zone of respiration, but be continually succeeded by fresh accessions of pure air. The ascending movement is also the natural system. I have had several trials with the descending atmosphere, but subsequent investigations led me to ascertain it not desirable. It is a common error to suppose that as carbonic acid is a heavy gas, the air vitiated by respiration and combustion tends to descend to the floor of any apartment in which it may be evolved, or that carbonic acid always tends to separate from it and accumulate below . . . . . unless an appropriate channel be provided for the ingress of the air, its movement cannot be controlled—the fresh air entering at or near the floor.*

The opinion of Sir James Clarke is given in his excellent work "On Climate and Consumption" published in 1841. When mentioning that to secure ventilation a continuous renewal of the air should take place in all inhabited rooms, he says—"The pure air should enter below, and the deteriorated air escape from above, a circulation according to the natural motion produced in fluids by difference of temperature, and prevented only by the ignorant interference of art. To understand the proper mode of ventilating, we have only to attend to the currents which take place naturally in all inhabited rooms. Air, as it increases in temperature, becomes loaded with watery vapour, has its weight diminished, and is forced up if means are not taken to prevent it. Now the air in an inhabited apartment being both heated and generally combined with a portion of watery vapour by respiration, &c., becomes specifically lighter at the same time that it is vitiated, and the most impure part rises to the roof. If it had the means of escape, it would be gradually driven out by an equal quantity of pure air entering below, which becoming heated and deteriorated in its turn, would in a similar manner ascend and escape; thus would a continued renewal of the air go on without any trouble on our parts—unless provision can be made for the escape of the ascending current of impure air, no admission of external air will secure ventilation."

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* Reid's Illustrations, 1844.

Dr. A. Ure, whose great scientific knowledge must be generally admitted, is even stronger in his opinion. He says that "the downward circulation of air every sound physiologist will deprecate as a noxious fallacy. The mephitic exhalations from the lungs having a temperature of 98°, occupy the upper part of a room, and if forced downwards by any means, must inevitably be breathed again and again before these particles can be discharged at the feet, in violation of the laws of specific gravity."*

Of a similar opinion seem to be the scientific men who were examined before the Select Committee of the House of Commons on Ventilation in 1835. Professor W. F. Brande, F. R. S., states "that in the ventilation and warming of buildings there are two essential points to be kept in view—first, the free escape of the warm air from above; and secondly, the admission of a compensating quantity of fresh air from below—and the fresh air should be admitted at or near the floor." Dr. G. Birkbeck appears to be of the same opinion,—approving of a full supply of cold air from below and the escape of the impure from above; and others who gave evidence were of the same opinion. Dr. Neill Arnott remarks, in his work on Warming and Ventilation, that "when the company in a room is so numerous that very much air must be allowed to escape above, and consequently as much to enter below, the air which enters in cold weather should be admitted through a passage expressly calculated for it."

Upon this point another writer remarks—"A descending movement not only returns the vitiated products on the system, but has also a tendency to produce disagreeable effects as it impinges on the head." "Again, cold air may be offensive at the feet, but it is much more dangerous if it plays upon the lungs and organs of respiration; hence the importance of diffusion before it comes in contact with the person." In truth, to admit the fresh air at the ceiling is just to precipitate the corrupt air, to be re-inhaled again and again, while the cold air falling through the vitiated air from its greater specific gravity, falls on the heads of those below it, to their great annoyance.

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* Official Report to the Collector of Customs on "Stove Furnaces," by And$^{\text{w}}$. Ure, M.D., &c.—*Arch. Mag.*, *Jan.* 1838, p. 33.

Another authority may be quoted, viz. Gavin Milroy, M. D., F. R. C. P., who in his "Notes on Barracks and Military Hospitals in Hot Climates" remarks—"The chief defect in most barracks is their faultily contrived and very generally insufficient ventilation, more especially during the night, when doors and windows of sleeping apartments are far too commonly closed, in all climates alike. Be it remembered that this is the very time in the four and twenty hours that a free and continuous circulation of pure renewed air is the most necessary for the maintenance of sound health and the prophylaxis of disease. . . . . It must always be borne in mind that it will never do to trust the ventilation to the men themselves. The means, therefore, for securing the continuous circulation of fresh air while they are in bed should be independent of them, and out of their reach and control. . . . . . No sufficient arrangement or provision is made for an ascending or vertical ventilation from the floor up to the ceiling; and yet this is a prime and fundamental point in all successful ordinary or natural ventilation—namely, that the cool fresh air be admitted at, or near to, the lowest part of the chamber, and the heated impure air be discharged at or near to the highest part. Attempts are sometimes made to have both the admission and the escape openings at the upper part of a chamber, distinct from but near to each other. But the plan is objectionable, and has never yet answered well in all seasons and weathers. . . . . . The roofs of barracks and hospitals in hot climates should always have ventilating turrets, to aid in the withdrawal and discharge of the vitiated air from the wards. . . . . . It is very needful to have a sufficient intervening space between the ceiling and the outer roof. This arrangement is necessary in all climates; in a hot climate, to keep the upper floors sufficiently cool during the day; and in a cold climate, to keep them duly warm. The interposition of a stratum of air between the outer atmosphere and the atmosphere of the chamber not only facilitates ventilation, but also greatly aids in maintaining an equableness of temperature." *

The very highest authority has now been given to show that fresh air should enter below and the impure heated air be discharged at or near the ceiling. A great and important point has thus been accomplished, and a sound principle in the art of ventilation established, whether it be carried on by natural or artificial agency. Keeping this essential ascending move-

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* Useful observations on barrack and hospital ventilation, especially in hot climates, will be found in the Report on this subject printed by order of the House of Commons in 1851,—and also in Notes by Dr. Milroy, in the Lancet, May 28, 1859, p. 530.

ment of the air in view, the reader will be enabled to form a correct appreciation of those plans which set these principles at defiance.

In the earlier Prison Reports, 1844–1847, plans were given the reverse of this,—the fresh air entering the cells at the ceiling and the foul air being drawn off near the floor. Many buildings were erected on this plan; but the best proof of the fallacy of the system was, that in buildings of more recent erection the process has been reversed,*—the fresh air entering below and the foul air being drawn off at the ceiling.

From the examination which the writer has made of many buildings in England and elsewhere—such as Lunatic Asylums, Hospitals, Prisons, and Barracks, some of which have been noticed—a very common plan at present in vogue is to admit the fresh air at the upper part of the apartment, and also to extract the vitiated air above. In some instances, as has been shown, the air is heated before it enters the room near the ceiling, and the vitiated air is removed at the same level; and in others direct inlets are not used, but the air enters above the doors from the corridors.† This mode of ventilation, although it is opposed to the opinions of scientific men which have been given, is not so absurd as admitting the fresh air at the ceiling and extracting the vitiated air below, as has been done at the Model Prison, Pentonville, and at other prisons which will be afterwards described.

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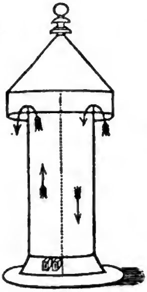
* In the wing first built of the Perth Penitentiary, the descending system was adopted,—in the wing last built it was reversed.

† Many examples might be given.—St. George's Hospital, London, may be instanced for the first method, and part of the Sussex Lunatic Asylum for the second.

FRESH AND FOUL AIR OPENINGS PLACED TOGETHER AT THE ROOF.

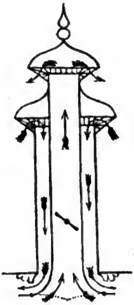
Notwithstanding the scientific evidence given, and that the Parliamentary Report of 1857, quoted page 51, coincides with these opinions,—namely, that the fresh air should be admitted below, and the vitiated air abstracted above,—still it will be found that plans are frequently brought under public notice, which militate entirely against these opinions, and set them aside. Some of these plans place together at the roof, both the foul air escape and the fresh air inlet.

Fig. 8.



One scheme seems to take up the idea of Dr. Arnott's double current apparatus, or rather that of Professor Daniel noticed in his Meteorological Essays (1845), vol. 1, page 19, but illustrative of a very different purpose. The patent ventilator (Fig. 8) consists of a metallic tube, placed at the roof of a building, with a hood over it to protect it from the weather. The tube is divided by a plate into two equal portions; and the principle of operation is to ventilate an apartment by the foul air going up the one half and the fresh air coming down the other.

Fig. 9.



Another plan (Fig. 9) on the same principle has been patented to effect the same purpose. The ventilator consists, instead of a divided tube, of one tube placed within another, with an annular space between the two;

the object being to ventilate the room by the foul air going up the inner tube, and the fresh air descending in the space between the two tubes, and escaping at a flange placed at the ceiling in order to spread it before falling into the room.

It must be obvious that by both these methods the fresh air must pass through the vitiated air at the ceiling before it reaches the zone of respiration of the inmates beneath. The regularity of action, too, must be liable to be affected by adverse currents from below. By the second plan, the heated impure air will be more cooled than by the first in its escape into the external air, because the inner tube is surrounded by cold air. The introduction of fresh air into apartments from the roof of a building by an opening within the vicinity of chimney pots cannot be considered the best source from which fresh air ought to be obtained for the occupants of a dwelling.

CONSTRUCTION OF ASCENDING FLUES IN BUILDINGS.

Before returning to the mode of ventilation which scientific men have recommended,—viz. to admit the fresh air from below, and to carry away the vitiated air from above at the highest altitude by means of one or more independent points of escape constructed in the building:—It may be remarked that air-flues often interfere seriously with chimneys, and that foul air descends sometimes in one and escapes at another. Dr. Reid suggests an important alteration in the construction of houses, viz. "the introduction of one principal chimney, into which the flues from all the apartments would be led; and that even for whole streets one large shaft would be sufficient." But without entering on these proposals, much benefit has been found in the greater draught of chimneys when they are constructed in the inner than when exposed to the action of cold air in the outer walls of a building.

There is little doubt that the ordinary conduits carried upwards within the walls of houses from the ceilings of rooms to the roof do not prove very effective for ventilation, especially during winter, because the combustion of a large fire will draw down the air from another chimney. The ventilating flue, therefore, instead of carrying off the impure air of the apartment, sends a current of cold air or back-smoke downwards, and the apertures are consequently soon ordered to be shut up. The cause obviously is the want of an adequate supply of fresh air entering the room to carry on the combustion. This defect may be to a certain extent obviated by the plan, proposed at page 47, of having an independent supply of air for the fire.

Ascending flues in buildings are constructed in various ways. Sometimes earthen tubes are carried upwards in the walls from the rooms to the roof; but unless provided with valves for closing them when necessary, a reverse current may take place. The plan may be noticed which received the sanction of the War Department as adopted at the Old and Brompton Barracks, Chatham, as also at the Wellington Barrack. As it at present exists (1859), a wooden shaft of about 12 inches square is placed at the side of the fireplace of each barrack-room. The shaft commences at the ceiling and is carried up to the roof. Its capacity is intended to give an average of eight square inches to each occupant." At the Old Barracks, Chatham, there are three floors—each room on the floor having its separate shaft. Three of these combined terminate at a louvre placed behind the chimney on the roof. When the wind is strong and the fire has a good draught, instead of a powerful upward current a reverse one takes place, especially on the upper floors, chilling during the night all persons within its range. This is merely another proof of the uncertainty of action which appertains to spontaneous ventilation.

SYSTEMATIC APPLICATION OF SPONTANEOUS VENTILATION TO A DWELLING-HOUSE.

The application of spontaneous ventilation upon a systematic plan was perhaps first brought under public notice in Sylvester's Domestic Economy, 1819, describing the various inventions of the late William Strutt of Derby, which had been applied at the Derby Infirmary; and for a long time these plans had many admirers. Indeed the revolving turncaps which aided the admission of fresh, and the escape of vitiated air from the building, were considered to be powerful adjuncts to ventilating spontaneously. As any plan, however, which involves much expense in the construction of domestic dwellings is generally wished to be avoided, a mode of spontaneous ventilation will be described which obviates the necessity of keeping the doors and windows of rooms open. The plan is simple and easily adopted while a house is erecting, and is one that the writer of this treatise years ago recommended.* Its principle is to view the staircase and the corridors and passages as the lungs of the house, and to convey into the house an ample supply of fresh air, which in winter may be warmed, and to have a free communication between every room and the staircase, even when the doors of the rooms are shut. This is done by means of a longitudinal opening over each door, concealed by the architrave and under the power of regulation by valves, with air-flues of earthen tubes placed in the walls, commencing at the ceilings of the rooms and terminating at the wall-heads under the roof, having a properly constructed roof escape.

The better to explain this plan, a short description may be given of a city-house built for a late scientific gentleman, in which these arrangements were successfully carried into effect. It was a self-contained house, in an open situation, and consisted of three floors above the street, and the basement story beneath. There was a current of eight square feet or section of atmospheric air, under regulation, introduced into the house by dry air-openings to the prevailing points of the wind. This supply of air was in winter moderately warmed, and entered the principal staircase at a temperature of about 70° Fahr., which was found to be sufficient to keep the staircase and passages at 60° F., even in severe weather. The different rooms of the house were thus supplied with warmed air, each room drawing its supply of air from the staircase by masked openings over and under the doors,—the area of these openings being equal to the sum of the areas of the throat of the chimney-flue and of the ventilating-flue which communicated with and carried off from the void space over the ceiling the vitiated air arising from lamps or the crowded state of the rooms. These arrangements were not intended to supersede in winter the use of open fire-places, but were auxiliary to it,—the volume of air entering the staircase being sufficient to supply all demand from the chimneys and ventilating flues without any great risk of back-smoke by one chimney borrowing from the other, or of drawing in the external air through chinks—evils very frequently found in houses where there is no provision made for admitting fresh air to supply the demand of the chimney. Besides the ordinary ventilation by the fire-places, fire-clay tubes in the walls, connected with the spaces over the ceilings of the rooms, conveyed away the vitiated air of lamps, gas, respired air, &c., as a slit or opening in the mouldings of the plaster works one and a half inch wide, all round each room, but which was not visible from below, admitted the heated air into the space above the ceiling, which communicated with an ascending chimney-flue of sufficient size and proportion to the area of the room, to ensure an ascending current. These escape-flues terminated above the ceiling of the attics, under the slates of the roof. The action of the escape flues was regulated, or was suspended when required, by means of a register on the orifice of each, which was operated on by an index in each room. By this very simple plan, a perpetual renewal of the air of the house went on, and no vitiated air or smoke could continue long in any of the apartments. The point of all others the most difficult to achieve,—viz. a steady ascending current by spontaneous action,—was thus obtained with as little risk of causing a reverse current by the open fires, as is possible by spontaneous ascent; and the object was obtained at a trifling additional expense in the construction of the house. The utility of the plan consisted in effecting a renewal of the air without being dependent on the constant attention of servants. Perhaps no better plan has yet been devised for applying spontaneous ventilation systematically and usefully to a dwelling-house.*

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* Communication by the writer in *Architect^l. Mag.* 1837; also his Prize Essay, *Trans. R. S. S. of Arts*, 1844.

Though ventilating flues in the walls are inapplicable to houses already built, still the communication between rooms and staircases, corridors, or halls, can easily be carried out, and the rooms by these means freely supplied with fresh air, which in winter may easily be warmed; and when fires are burning, there would be a free circulation of air in the room, and offensive currents arising from the room doors being left open avoided—or when the doors are closed people could not be shut up in a close room. Should it be preferred that the fire be provided with an independent supply of air for combustion, a circulation of air could still be maintained in the room by means of the communication and an Arnott ventilator in the chimney.

Although the plan described of admitting air into rooms was long since proposed, it has not been much applied. Amongst other plans for the ventilation of rooms, an open space was left between the upper part of the architrave surrounding the door and wall on each side, and likewise an open space between the casing and the lintel. An old scheme introduced air into rooms between the folding of the sash frames. By another plan applied many years ago at St. Thomas's Hospital, London, in every second window, about 1½ inch of each pane on the bottom of the upper sash was cut away, and the air which entered between the sashes was directed in an angle towards the ceiling by means of a glazed hinged frame resting upon the lower sash.

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* *Sup. Encyc. of Arch.*

AIR APERTURES IN BUILDINGS.

The admission of fresh air, as may be learned from what has been said, is not unattended with difficulty, and requires much consideration. As a general principle, the air, while it is supplied in abundance, ought, if possible, to be diffused, in order to avoid currents. This to a certain extent may be effected in the following manner:—Supposing the entering current of fresh air to be compared to the brisk flow of a stream subsiding gently into smooth water, the air conveyed by a conduit into the building may, so soon as it enters, be broken and divided into smaller streams, and ultimately diffused over the room by numerous perforations, and thus flow in copiously though imperceptibly. The greater the amount of fresh air that can on this principle be admitted into crowded rooms without giving annoyance, the better. Such an arrangement as this, however useful, cannot be often adopted, from its requiring a building to be constructed for it. A much more common mode, therefore, is to admit the fresh air at inlets in floors and walls. As reference has been made at page 31 to having direct air-inlets into barrack-rooms, the mode may be noticed as now applied at these barracks mentioned page 00. It consists of incisions in the outer walls to the open air. There are two in each room about 12 inches square, placed near the ceiling. The apertures in the room are concealed by plates of wood set at a slight angle, and are covered with perforated zinc for the purpose of checking the current of cold air from pouring down on the persons below. The mere deflection of the air, however, cannot hinder the cold down-draught from being offensive. Thus it will be very probable that during the night, or in cold weather, the apertures will be closed. This is supported by the opinion of Sir J. F. Burgoyne on the ventilation of barracks. He says (Par. Rep. of 1857, p. 126)—"Openings are made from the open air outside the building, below for the admission of fresh air, and above for the escape of foul, in various fanciful ways; but although the cold draughts are so inconvenient that every endeavour is practised to obstruct the inlet, the circulation is so sluggish that a regulation has been established under medical opinion, that every barrack-room in England should contain 500 cubic feet of air, and in hot countries 600 per man—manifestly, as I conceive, as a remedy for imperfect ventilation; and notwithstanding that regulation, and the measures taken for establishing a circulation, the air in a barrack-room that has its complement of men is generally in an unsatisfactory state, which is more particularly experienced after they have been some hours in bed.

"I am very much inclined to believe that an efficient and wholesome circulation of air, and one not attended with discomfort, can only be obtained for barracks by some artificial power, either for the forcing in of fresh air or the drawing out of the foul."

POINTS AT WHICH AIR MAY BE ADMITTED AND DIFFUSED IN ROOMS.

Buildings exist in so many different forms, and are used for so many different purposes, all requiring ventilation, that no plan can be given for this purpose, however good it may be in particular cases, that would be applicable to them all. A great difficulty has been alluded to in obtaining an adequate supply of fresh air for a building,—viz. to get it sufficiently diffused to avoid giving annoyance to the occupants. The staircase in a dwelling-house of the kind previously mentioned obviates so far the difficulty, but in another building where such a plan is inadmissible, the air is equally required to be diffused. The extent of the diffusion circumstances will regulate, but where practicable, uniformity of temperature is desirable for comfort and salubrity. It has even been proposed for the room of the invalid, that both the walls and floor be made porous for the admission of air, and the ceiling likewise for its escape. Perforated floors of wood or iron have been tried with different degrees of success. They have been found offensive from the dust brought in with the current through the matting or hair-cloth; to obviate which, various expedients have been tried. Dr. Reid recommends a mixed movement, by which a descending current is made to precipitate the dust directly downwards, while an ascending current is made to carry off the moisture from the breath and the products of combustion and respiration;—but these schemes are too complicated. Mr. Gurney, of London, carries the idea of the downward current farther, as will afterwards be noticed. But no plan of admitting fresh air into rooms seems less desirable than that of allowing it to enter through gratings placed in floors and passages;—they are not only offensive when walked upon, but they become receptacles for the sweepings of rooms, and dust and refuse are collected in them. To stand upon such cold-air openings in winter is highly injurious.*

In other plans, as has been shown at page 85, the opposite course is adopted, and it is proposed to admit the fresh air at the ceiling, thus reversing the natural law.

Other methods have been tried with partial success, in which the fresh air is introduced midway, or at different heights in apartments by apertures concealed from view. Much depends on the purpose to which the apartment is applied; but so long as the manifest absurdity is avoided of sending back the products of respiration and combustion to be re-inhaled, no great harm can arise from them. It is difficult to devise a plan by which a large supply of fresh air can be without inconvenience admitted into occupied apartments, whether partially filled or crowded with people, unless the air is previously slightly warmed; and even when warmed, the air, if in motion, when it comes in contact with the person, will, from its abstracting heat, feel not so warm as it really may be. To admit the air warmed at the ceiling or roof of a building, in order to heat the lower part of a room, is hardly possible, and thus the previous point is forced back upon us,—to raise the temperature, wherever this is practicable, of the staircase, corridors, and passages in buildings, and to have a free communication between them and the rooms; or if this cannot be done, to supply each room with an abundant supply of fresh air at the basement, tepidly warmed in winter, and taken from a pure source. In summer the same air can be made use of for ventilation without being warmed; and it may in some places be made to pass over beds of odoriferous flowers —or moisture may be imparted to it by passing it through a perfumed shower before entering the apartment or building.

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* In a school-room lately built, where cold air was admitted from gratings in the floor, the teachers, both male and female, suffered from swelling of the legs; and when the cold air came in from above, they suffered from catarrh and bronchitis.

The skirting, wash-board, surbase or dado in rooms, present, with the ascending system of ventilation, the most convenient position not only for the admission but for the diffusion of the air. The whole space around rooms could thus be made available for this purpose; and in a similar manner a corresponding connected aperture may be made round the room at the ceiling cornice,—the inlet below and the outlet above. The inlet below can be concealed by means of an ornamental trellis, or by perforated zinc; or porous cloth of different textures, coloured to harmonize with the painting of the room, might be used. This might be even carried farther, if more air were required in crowded apartments, by having what have been termed "breathing walls," *i.e.* panels so constructed in the walls as to admit air through hair, woollen, or cotton porous cloth, so modifying the current as not to be offensive. Another plan might be adopted, viz. to have coils of hot-water pipes under tablets in rooms or corridors, of forms more or less ornamental, or made to resemble pieces of furniture, from which both air and warmth might be evolved over a room, or any number of rooms. All these expedients have been in many cases carried into effect by the writer, and being thus based on experience and success, avoid both theoretical and expensive abortive schemes.

The Patent Small-Pipe system is admirably adapted to carry out these views, and will be yet more appreciated than it has been, from the great facility with which it can be combined with a simple and efficient system of ventilation. The late Dr. Andrew Combe says of it, in his "Physiology," (p. 251), that by this system "ventilation can be carried with safety to any extent. . . . All that is necessary is to have the cold air from without conveyed into the lower part of the ornamental metal box or case in which the coils of pipe are contained, and to have proper apertures at the top of the box to allow the warmed air to escape into the room. To permit the exhaled air to get out, openings are left in the ceiling of the room. . . the entrance of warm external air and the issue of vitiated air—or in other words ventilation—can be regulated at pleasure, without any risk either from draughts or from the entrance of cold damp air. . . The efficacy, economy, safety, and agreeableness of warming by the above plan can scarcely be overrated, particularly in large buildings, hospitals, and places liable to fire." The advantage of this plan is that air-flues in buildings, which in cases of fire often act as conduits for the flame, are avoided.

Besides this arrangement, so highly lauded by Dr. Combe, these small hot-water pipes readily admit of being placed behind skirtings or panels in rooms, so as to warm, in winter, the fresh air before it enters, or the air may be warmed in a chamber in a lower floor, and enter the dwelling-room through a perforated skirting or wash-board.

PART III.

EXAMPLES OF SPONTANEOUS ROOF-VENTILATION.

A few illustrations will now be given, to show the difficulty which has always been experienced in getting roof-ventilators to act with certainty, and the efforts which have been made to overcome this by improved plans of spontaneous ventilation.

The first is from Tredgold, showing the manner in which he conceived the difficulties of ventilating a church or hall could be overcome; for the same difficulty has always been experienced,—namely, that the warm air of the room will not readily escape at the roof opening into the external atmosphere, but on the contrary, that objectionable streams of cold air will fall upon those within its range. This disagreeable effect is also experienced in a crowded room when a window is unexpectedly opened, and even by those who are sitting near a large window when shut, because a cold descending current is created in the air in contact with the cool surface of the glass. The practical difficulty in such a building is how to get the ceiling ventilator to act properly, or to obtain a steady or certain upward current to convey into the atmosphere the impure air which has ascended to the ceiling. Everyone who has attended to the subject is aware of this difficulty, and hence the various forms of foul-air escapes placed at the roofs of buildings. For instance, in the ordinary bent roof-ventilator made of zinc (see Fig. 6, page 59), the air in most cases is checked at the orifice, and instead of the foul air going out, it is pressed back as if by a downward current. This does not happen in the case of a common chimney, and yet it does with the ventilating pipe,—obviously because the air wants a sufficient elevation of temperature to have the ascensional force sufficient to pass it freely into the denser air without; or in other words, there is too little difference between the specific gravities or weights of the internal and external columns of air.

Now this risk of an occasional descending current is a defect which peculiarly belongs to spontaneous ventilation, and it might be expected that every effort would made have been to avoid it; yet it has been recommended (upon what principle it is very difficult to guess) to make a descending current at the roof, and to supply fresh air to the room from that point. It is in vain to say that the cold air entering there will force out an equivalent quantity of foul air at the same point, for the annoyance from the descending cold-air current still remains.

Tredgold endeavoured to overcome the risk of a descending current, but a glance at his diagram will show that his plan could hardly prevent it. It might be that in a summer day the vitiated air at the ceiling was of about the same temperature as the external air, when the current would nearly cease; or secondly, the air within at the ceiling might be at 60° or 65°, and the external air at 32°, and still the ventilation would not be efficient,—the cold air at the ceiling rushing in, and the foul air not freely escaping,—or a portion of it might pass out through the same aperture,—and this because there was not sufficient difference of temperature and elevation of the chimney or foul-air escape, to enable the air of the room to force its way through the denser atmosphere. This point has been fully dwelt upon, because it is the cause why so many failures in ventilation occur. It is next to a physical impossibility to ventilate a crowded building spontaneously in this manner, yet it is constantly attempted. Fig. 10 is an example given by Tredgold, in which he recommends that the ceiling of an apartment should be "domed or coved, arched or groined, and that the ventilating tubes should ascend from the most elevated parts, as these are the most favourable for ventilation, both as regards expelling that portion of the air which is most vitiated, and as giving a higher column of rarefied air to cause its ascent." But there should be the means of opening and closing the apertures, so as to regulate the quantity of ventilation at pleasure. This may be easily effected by balancing with weights the plate A which closes the aperture. The motion may be communicated by a line or wire over the pulleys P P. All that is necessary is to place a part or the whole of the balance weight at H, the part of the wire which is taken hold of to move it. Tredgold remarks that this method is nearly the same as that which the Romans employed to regulate the temperature of the Laconicum or sweating-room.

Fig. 10.

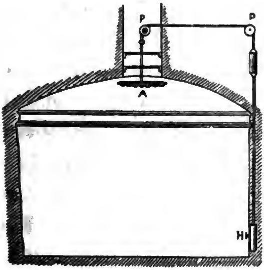

Fig. 11.

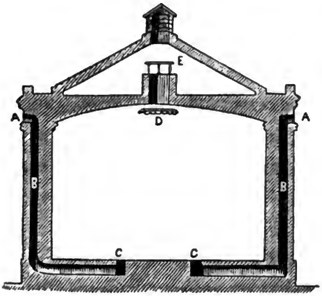

Fig. 11 is another example from Tredgold, showing his plan of ventilating a church. He remarks that "the ventilation is most difficult to maintain in close and gloomy weather. Suppose we wish to promote ventilation sufficient to prevent the internal air from being of a higher temperature than 5° above the external air; now if the external air be at 70°, we shall not be able to keep the internal temperature down to 75° with a less escape of air than 2½ cubic feet per minute for each person; because each person will heat quite that quantity of air 5° in a minute at these temperatures. When a church contains 1000 persons, and the height from the floor to the top of the tube is 47 feet, we have to find the sum of the upper apertures that will allow 2500 cubic feet of air per minute, which is easily calculated by the rule given;—that is, 2500 divided by $20\sqrt{49} = 12$ square feet. When the ceiling is level, this area should be divided among five or more ventilators dispersed in different parts of the ceiling; but in a vaulted or arched roof, perhaps three will be better placed on the highest part of the ceiling as at D (Fig. 11.) The openings for admitting cold air should be about double the area of those at the ceiling. The air should not be taken from very near the ground nor from a confined place. In a new building it might be prepared with flues for cold air down the piers between the windows, for the air to enter at A in the frieze under the cornice, pass down a smooth flue, and rise into the church through gratings in the floor C C; and by disposing some of these flues on each side of the church, they would act with the wind in any direction. The flues for admitting cold air may have their entrances at A A at any lower points, and it is not necessary that they should be in the walls;—indeed the same effect may be obtained in various ways according to the case to which it is to be applied."*

Such are the different arrangements proposed by Tredgold for ventilating by spontaneous means more than thirty years ago, and which have been very generally adopted in buildings with varying degrees of success. The frequent complaints, however, of defective ventilation in churches and other places, show that the rules he laid down were founded more upon theory than practice; for the vitiated air will not pass from the ceiling in the ratio given, but on the contrary more frequently cold air comes down, bringing with it the products which had previously ascended.

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* Tredgold, 3d Ed. 1836, p. 168.

Dr. D. B. Reid, in his Illustrations of "Ventilation," at a much later date, has given many examples of the various modes of applying spontaneous ventilation to buildings, taking advantage of every means to induce a current.* But it may well be supposed that with every desire to take advantage of the natural movements of the air for securing its discharge, he found that it could not be relied on to obtain a uniform and determinate movement; hence he had recourse to other agencies.

Fig. 12.

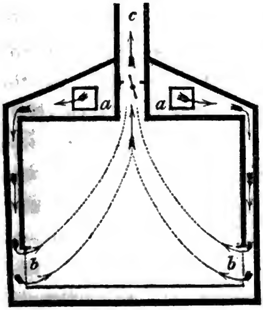

Fig. 12 is supposed to be the section of a church, in which *a a* are apertures for admitting the fresh air by openings in the gable under the roof. The fresh air, passing down vertical flues in the walls, is discharged at the lower part of the room. Diffusion is given by a deep dado, by which the air enters the building, passing through wire gauze, perforated zinc, or an open texture of cloth. The discharge of the air is regulated by the valve *c* in a central channel by which the air escapes.

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* Reid's Illustrations, p. 126, 1844.

Fig. 13.

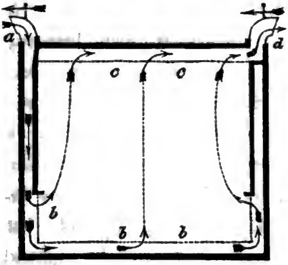
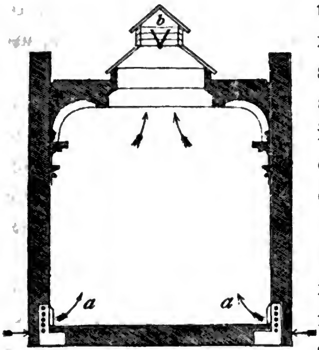


Figure 13 is another example from Dr. Reid's work, of what he terms "mixed ventilation." The valves and apertures being set to the wind, supply abundance of air by a plenum impulse through *a*, and also contribute to the discharge by favouring a vacuum impulse at *d*. In this sectional figure the wind is supposed to be from the west. *b b* are the points where the fresh air enters the apartment, *c c* where the vitiated air escapes at the ceiling, passing out at *d*.

Some may consider these examples more theoretical than practical; and indeed the experience of the author has convinced him that it is easier proposing to bring fresh air downwards, through flues, to the floor before it ascends, as these illustrations show, than to make it operate effectually. And even after the expense has been incurred of making wall-flues for the purpose, this operation cannot be relied on unless artificial or mechanical agency be employed to force a current,—simply for the reason already stated, that the temperature of the vitiated air at the ceiling is too little above that of the external air. It is just as probable, indeed, that by the vertical flues the current may be reversed, and that the mephitic air, instead of going out at the ceiling, may be sent back; and there is even a chance that the current may pass up the vertical flue.

Another plan of admitting the fresh air when ventilating spontaneously has been successfully carried into effect by the author of this work. The annexed section (Fig. 14) shows the mode lately adopted in a large building in Edinburgh.* An open skirting 9 inches deep runs rounda room 65 feet by 25 feet and 20 feet high, having a fresh-air flue under the flue which follows the skirting. Behind this skirting patent hot-water tubes are placed, so that the room can either be heated by radiation from the pipes, or fresh warm air admitted in an instant. The ceiling is coved, with a skylight having ventilators with louvres at the roof, regulated by valves working with bell wires so as to be opened and shut at pleasure. Much has been done to carry out an efficient system of spontaneous ventilation, but which of course is liable to the defects noted at page 101.

Fig. 14.



It is a generally-admitted fact, certified by the experience of scientific men, that to have a complete control over the ventilating currents, especially in public buildings, there should be, when possible, only one opening for the ingress and another for the egress of the air. The annexed figures 15 and 16, illustrative of this principle, exhibit a plan which was carried into effect by the author for the spontaneous ventilation of a church, and from which its advantages may be judged. It embraces almost everything that can be done to perfect the process; still there must ever be an uncertainty as to the uniform action of currents, unless directed by artificial agency. Fig. 15 is a longitudinal section, and Fig. 16 a transverse one. *a a* are fresh-air inlets, taking advantage of the prevailing point of the wind, but only one inlet is used at a time. The fresh air enters a chamber where in winter it is moderately warmed by hot-water pipes; it then enters air-trunks or flues in which hot-water pipes are also placed, which carry the heat to the extreme end of the church. The air is diffused over the whole building, entering it by means of perforated zinc apertures

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* The Office of the Life Association of Scotland, Prince's Street.

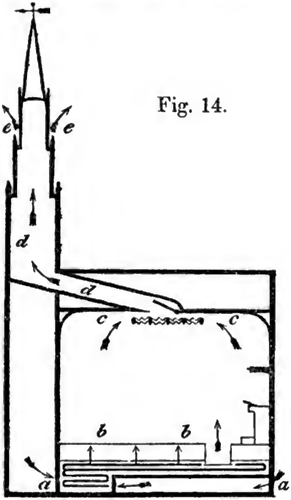
Fig. 14.

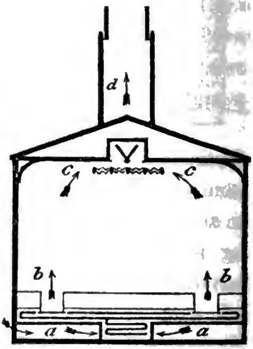
Fig. 15.

running from end to end of the passages, the pews being raised a few inches above the passages for this purpose. The vitiated air passes through the centre of the coved ceiling by one very large circular opening partly concealed by plaster-work, and thence into a chamber over the aperture. The opening between the church and the chamber is regulated at pleasure by means of one valve, and the foul air is led from the receiving chamber by a large shaft, inclining upwards as much as the roof will permit, until it reaches the spire, where it is received into another chamber and escapes through luffer boarding at a higher altitude into the atmosphere. It seems to operate as well as any plan acting spontaneously can do.

By the aid of the architects* the author had the opportunity of carrying into operation what he desiderated,—viz. to obtain as much advantage as was possible from spontaneous ventilation. Other examples might be given of ventilation by spontaneous means, put in practice by the author, where the fresh air is admitted directly into the building. In a church in which the pews are elevated a few inches above the aisles, small pipes are placed entirely round the aisles, and the fresh air comes through perforated zinc to break the force of the current passing over the pipes and receiving an increase of temperature before entering the church, the vitiated air being led, as in the other example fig. 14, from the ceiling.

Many other examples of buildings ventilated in a similar manner might be described. In a large pubic hall with which the author was connected, the vitiated air escapes from a high domed ceiling, regulated by valves, from a central turret and louvre into the atmosphere; and the air is warmed in winter, as in the previous example, by means of hot-water pipes, and, regulated both in temperature and humidity, is diffused over the building.

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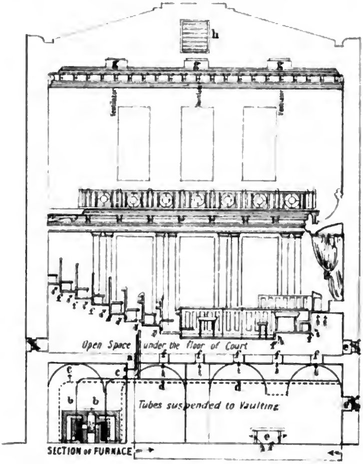
* Both in this and two preceding examples, and in some of those which follow, the author was much indebted to the architects for their co-operation.

In other cases, where no spire or tower exists to facilitate the escape of the vitiated air into the atmosphere, recourse is had to a revolving zinc turncap with a wind-vane attached to it, the size of which must be proportioned to the cubical contents of the place to be ventilated. The author has, however, applied a method which is less objectionable in an architectural point of view than a large turncap at the roof of a building. It is to place a cylinder within a louvre which revolves by means of a wind-vane, so that it always turns its back to the wind,—see fig 7, p. 59. This is a most useful adjunct to spontaneous ventilation.

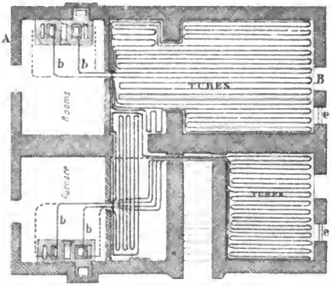
The four Courts of the Lords Ordinary, as well as other Courts at Edinburgh, are ventilated by spontaneous means. In the Lords-Ordinary Courts warmed by the author, the fresh air, taken from a pure source and at some elevation above the ground, passes into horizontal flues below the skirting. Behind these a large number of the patent small pipes, heated in same manner as in fig. 14, are placed round the Court, and the fresh air passing over these pipes, regulated as circumstances may require, is elevated in temperature without being injured in purity, and, entering the Court, is diffused over it, which is thus heated by warm air and radiant

PLATE I. Page 109.

ILLUSTRATIONS OF SPONTANEOUS VENTILATION


h
g
g
g
Ventilator
Ventilator
Ventilator
f
Open Space under the floor of Court
a
c
c
b
b
d
d
Tubes suspended to Vaulting
e
SECTION of FURNACE

SECTION FROM A TO B ON PLAN.



PLAN OF THE BASEMENT

heat. The foul air is led off by one large aperture under control into the atmosphere. Many other buildings have been arranged in a somewhat similar manner, such as the Advocates' Library in Edinburgh, Marischal College, Aberdeen, &c. &c.

The Justiciary Court, Edinburgh, also affords an example of totally different arrangement, in which a pleasant and equable mode of warming is combined with natural ventilation. Plate I. represents a plan (fig. 1) and section (fig. 2) of the Court-house as warmed by Mr. A. M. Perkins of London with the patent hot-water apparatus of which he is the inventor.

> *a a*, Expansion tubes—*b b*, ascending tubes from the furnaces—*c c*, filling tubes—*d d*, heating tubes—*e e e*, openings for admission of cold air—*f f f*, openings for admission of warm air into the Court—*g g*, ceiling ventilators—*h*, luffer at roof.

The patent hot-water tubing, heated by two furnaces, is suspended to the vaulting of a room under the Court, and spread over the whole space like a floor. The cold fresh air admitted into the vaults ascends between the spaces of the tubing, and enters by nine openings in the vaulted ceiling into a space under the floor of the Court. In order to diffuse the warm air equally over the Court, small lateral openings are made under the seats, and in every situation where they can be obtained, but none are made in the floor itself; through some hundreds of these openings the warm air rises into the Court. The ventilation is effected in the common or spontaneous mode;—openings provided with registers "are made on the ceiling into the roof,* from which an opening with luffer boarding permits the escape of the warm air into the atmosphere."

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* Richardson on Warming, &c., p. 47.

Numerous examples of spontaneous ventilation might be given, showing the useful application by the author, of the method of admitting air into apartments, passing through coils under ornamental pedestals as recommended at page 97,—such as the Natural History Museum, the College Library, the Signet Library, the Record Room, Register House, the Merchant Maiden and Stewart's Hospitals, Edinburgh, the Commercial Bank Offices at Edinburgh and Glasgow, and several Churches, Mansions, &c. In these buildings fresh air is warmed without taint or impurity. In England this arrangement has been extensively carried into effect by Mr. Perkins of London.

Amongst other examples of large buildings recently erected, to which chiefly spontaneous ventilation has been applied, may be noticed the Wellington College at Sandhurst, which, with the land belonging to it, has cost about £100,000. It is a quadrangle of 260 feet in length, by 154 in width, the sides of which are the north and south wings of the building. This building, which the writer has examined, stands in a somewhat exposed situation. The towers which lead to the sleeping-rooms are partly used as ventilating shafts through which a constant flow of pure air is kept up, while foul-air shafts provide for carrying off the vitiated atmosphere from below. The partitions which separate the boys' rooms are carried up to within a few feet of the ceiling, so that the fresh air circulates freely along the whole length of the dormitory from north to south. The vitiated air from the dormitories is carried off by means of a horizontal wooden conduit, perforated with small holes, to ventilating shafts in the angles of the towers. In these shafts ring gas-burners are placed for the occasional rarefaction of the air. The fresh air is heated in winter by hot-water pipes, and enters the corridors of the dormitories through gratings in the floor. The same method of admitting the warm air is adopted for the Hall and School-rooms. From what has already been said about the inconvenience arising from admitting air by floor-gratings, as also extracting vitiated air at the lower part of rooms, it is sufficient merely to point it out, to show that there is little improvment of the system adopted at this building. It may be doubted whether any advantage can be derived from the dormitories communicating at the upper part of the partitions within a few feet of the ceiling; for instead of "fresh air circulating freely along the whole length," the impure air will be quickly conveyed from one sleeping-room to the other.

Many illustrations might be given of buildings recently erected or now erecting, chiefly ventilated upon the spontaneous principle; but there is so little novelty in the processes adopted, that it is not necessary to enlarge on them. It must be, however, more useful to refer to examples than to generalize on the subject. Reference may be made to the large edifice now erecting for a Marine Hospital at Woolwich. The numerous wards on different floors enter from a long corridor, and are about 60 feet in length, 25 in breadth, and 16 feet high. They have open fire-grates. Into these there are no direct external air-flues. The smoke from the open fire-places is made use of to aid the escape of the vitiated air. Near the ceiling, small openings admit the air from the rooms into an open space surrounding the earthen pipe in which the smoke from the fire ascends, and which passes up the whole height of the chimney. It is not, however, free from the risk of the fumes escaping from the pipe into the rooms. In summer such a process of ventilation can be of little service.

The difference of opinion that exists as to ventilating arrangements is shown by the following extract from the "Builder" in 1858 on "Hospital Construction and the arrangement of Wards."* The writer of the article recommends that wards be constructed, in order that they may be lighted from windows on both sides, and urges the importance of light in a curative point of view. He recommends that wards should not exceed 30 feet in width, have no more than 32 beds—16 on each side—with a window to every two beds. The windows should reach from within 3 feet of the floor to 1 foot of the ceiling. Each bed should have from 1500 to 2000 cubic feet of air space." He farther states that "few greater mistakes can be committed in hospital construction, as far as light and ventilation are concerned, than placing the windows at one end of a ward, or even at both ends, with beds ranged down the sides, their heads to the dead wall." —"But there has been a greater mistake in the case of Netley Hospital, where not only has this most objectionable principle of construction been adopted, but also that of covering the windows in on one side by a glazed corridor." "Our military buildings have been and are most unfortunate in their arrangements. The unhappy Netley Hospital has been copied in its wards and corridor arrangements from such places as Chatham Garrison Hospital, Woolwich Hospital, &c. In fact, there are few military hospitals in which the error does not exist in one form or another." "A great mistake and a lamentable misfortune is Netley Hospital. But let us hope we have seen the last of such fatal blunders in hospital building"[*] The writer of the preceding article appears to be favourable to the spontaneous ventilation of wards. He observes, that by the proper construction of a building "that nature will renew the air if left to herself, which is the best plan." No doubt, by improved construction advantages will be obtained, but it has been shown that while the warming of buildings was generally successful, the removal of the vitiated air spontaneously, or the complete renovation of the air, was not so. The opinions of different authorities corroborating those of the author on this subject have been already given. Tredgold's were fully quoted at pages 101 and 102. One writer observes—"Mr. Tredgold truly remarks that ventilation is most difficult to maintain in close and gloomy weather;"[†] he ought to have added, that it is impossible to obtain adequate ventilation under any circumstances according his system. For, as the whole basis of spontaneous ventilation depends on the possibility of producing a current in the air, it will be obvious that when the exterior atmosphere is in a state of repose, and more especially when it is saturated with water, that it will be difficult or rather impossible to create an adequate current for ventilation."*

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* Vol. xvi., No. 816, Sep. 25, 1858, p. 641.

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[*] Page 691, vol. xvi., No. 816.

[†] Tredgold, page 166.

The defects attaching to spontaneous ventilation having now been pointed out, it must sooner or later come to be generally acknowledged that the idea of attempting to ventilate a crowded building in this manner is a mere delusion. It is based on a fallacy,—and were the principles upon which a thorough system of ventilation depends properly carried out, spontaneous ventilation never would be proposed, or even be attempted to be applied to any building where a number of persons are to be assembled together. In such a case, spontaneous ventilation is a mere misnomer and a burlesque of the word ventilation. Equally so is the prevailing error that because an apartment or hall is made high in the ceiling, it does not require ventilation;—it is forgotten that whether the ceiling is flat, domed, or circular, a great height merely implies an increased cubical capacity, and consequently a larger space for the collection of impurities from respiration and combustion,—more particularly of gas, which so materially injures the air. In fact, without proper provision for ventilation, the idea that there is any advantage in high ceilings is a fallacy, and its prevalence inclines one to imagine that notwithstanding all that has been written and said, the importance of a regular supply of pure air, and the constant renewal of that which has been rendered impure, is either but too little understood or most improperly neglected.

It may be useful to close this chapter on spontaneous, natural, or self-acting ventilation, by giving a short extract from the Parliamentary Report of 1857, showing the result of the experiments made by the Commissioners at the Wellington Barracks. They recommend, "that instead of 500 cubic feet, 700 to 800 cubic feet of space should be allowed per man, or, as in the case of the Wellington Barracks, that only 10 persons should occupy the space allotted to 16, and that these regulations be enforced throughout the whole of the United Kingdom;"* . . . "That there should be exits provided for the spent air near the ceiling, either by perforations in the cornice at different parts of the room;† by apertures made near the ceiling, or by one sufficient aperture leading into the chimney, with a rarefier in case of need, to such an extent as to remove from 15 to 20 cubic feet per minute for each occupant."—That a rarefied atmosphere may be created "in a metal pipe, inserted in the ceiling, leading into the chimney, in which a gas jet should be kept burning both day and night, in summer and in winter. An upshaft draught would be created, which would act as a most effectual means of ventilation."‡—"That in order to effect an agreeable and pleasant ventilation, and to prevent currents of cold air rushing from the doors and windows in the direction of the fire, it is recommended that the supply of atmospheric air for the support of combustion be provided from some independent source, such as an air channel or tube, under the floor, in communication with the external air. The ventilation of the room would then be carried on by proper apertures,—that is, independently of the air-supply to the fire."* "The Commission is decidedly of opinion that so long as the fire-grate is studied with a view to a two-fold application (heating and ventilation of rooms) it will not succeed well in the performance of either."†

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* Theory and Practice of Warming and Ventilating Buildings, &c., by an Engineer, London, p. 133.

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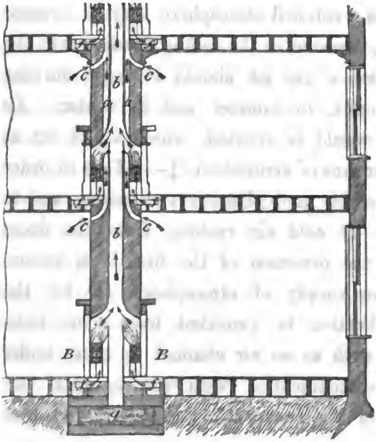
* Par. Rep., p. 99. † Do., p. 94. ‡ Do., 1857, p. 92.

In the same Report the attention of the Commissioners was directed to the plan of a dwelling-house which "appears to meet all the requirements of a more efficient system of heating and ventilation." . . . "Its success cannot be vouched for, but we consider it as an experiment worthy of trial."‡

The annexed section (Fig. 17) shows the two lower floors of a house of four floors with eight rooms, and illustrates the principle on which it is proposed to construct dwelling-houses. The fire-places are placed back to back against the partition wall, and the products of combustion from these are conducted into a single vertical flue (*b b b*) of ten-inch diameter, made of clay pipes; while to supply the fire, air-ducts or channels *(f f)* leading from the

Fig. 17.



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* Par. Rep., p. 94. † Do., p. 95. ‡ Do., p. 96.

external atmosphere are introduced beneath the flooring in each room and opening to the fire through the hearthstone. Above the fire-place in each of the rooms the vertical flue (*b b*) would have a descending branch flue to fit into the throat above the fire-grate, constructed to be air-tight in relation to the surrounding air-chamber. In this plan it will be observed that the products of combustion from all the fires of the house are collected into one flue with the kitchen fire at bottom, so as to ensure more or less heat passing up the chimney at all times of the year. Around the smoke-flue (*b b*) it is proposed to leave an open circular space (*a a*) passing up the whole length of the chimney from the top of the kitchen flue (B) to the full length of the shaft. This chamber might be made of an octagonal form, and would become the means of relieving the rooms of the vitiated air,—the heated smoke-flue causing a current to rise through it, and "passing off above by apertures beneath the chimney tops." "Thus the fire being supplied with air by a sufficiently capacious air-duct, the constant loss of heat, and draughts from windows and doors, are obviated, while the air of the room is kept pure by the passing away of the impure air," . . . "and without the possibility of the passage of smoke through the apertures intended for ventilation."

This assertion is easier made than proved. With the action of eight fires into one clay tube, there can be no guarantee for the durability of the tube, nor that smoke will not escape into the rooms through these apertures. The Report states, "that in the event of one smoke-flue being liable to counter-draughts descending from fires on one side to those on the other"—a thing most likely to occur—" two smoke-flues might be fixed in the air-chamber, or the single flue might be divided by a diaphragm or partition, either of which plans would effectually prevent ascending currents from one room descending into that of another room."

Amongst the advantages pointed out as attending the constructing a house in this manner, would be " the facility afforded by a perfectly straight and vertical flue for brushing and cleansing." It is also advised that a perfectly close tight damper be fixed in the throat of each fire-place communicating with the vertical flue, " to shut off any particular room from the smoke-flue during the summer months when fires are not required; . . . that double panes of glass be used in small rooms, and double sashes in large rooms."*

This scheme seems by far too complicated to be of much utility. One main feature of it, viz. keeping the room pure by passing away the vitiated air, would be rendered nugatory in summer if eight rooms were dependent on the heat of one fire.†

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* Par. Rep., p. 97.

† The same idea of using open fires (shown in fig. 17) has been proposed for ventilating the Wards of an Hospital; but each fire to have its own flue, and all the flues conjoined. Such a plan can be of little use in summer, when ventilation is so necessary; and in winter, unless the fires are kept always vigorously burning, the effect of the ascending currents will be inoperative, and descending ones take their place.

CHAPTER III.

FORCED VENTILATION BY THE AGENCY OF FIRE AND GAS HEAT.

PART I.

FIRE HEAT.

THE difficulties which have been pointed out to get rid of the contaminated confined air of apartments by natural means have led to much ingenuity being devoted to overcome them by forced ventilation. But when considering this, the error must not be fallen into of not distinguishing between the ventilation of domestic and public buildings. What is meant by the inadequacy of spontaneous ventilation, is its insufficiency chiefly when it is applied to apartments where numbers of people are congregated, and where strong causes of atmospheric vitiation exist. In domestic buildings, where few are assembled, the means have been pointed out how, generally speaking, to a considerable extent spontaneous ventilation may, by attention, be obtained, and houses be improved in comfort and salubrity.

It has been shown that the principle upon which spontaneous ventilation should act, when operating efficiently, is the producing of an adequate current in the air to carry off that which has been vitiated. But the reasons have been explained—(pages 99, 100, 101, 102, and 112)—why it cannot be relied on to do so in crowded buildings. It has been already shown, besides other reasons, that the foul air, which at first ascends to the ceiling, is not sufficiently heated to be forced in a steady current current into the external atmosphere, and that the ventilating chimney or shaft, in general only a few feet above the roof, is not sufficiently high to assist the ascensional movement.

Cognisant of the facts which operate against a spontaneous renovation of the air in close places, the scientific observer regards with satisfaction the application of a motor by which the movement of the air within buildings can be regulated and controlled. The Marquis of Chabannes remarks in 1814, that he "resolved to take out a patent for his Caloriferé, and to make public his long-meditated plan for regulating the temperature, conducting and purifying the air in dwellings, and that his chief aim in this was the ambition of being known as the author of forced ventilation." But while every credit is due to the originality of the Marquis, still the claim he makes cannot be admitted, as the subject of forced ventilation was known and practised long before his time. Obviously the first motor that would present itself to the human mind would be the heat arising from the combustion of fuel:—warm air ascends "as the sparks fly upward," is the observation not of years but of centuries. The earliest noticed account which the author has observed of the application of fire heat to extract impure air and promote ventilation, appears in the Transactions of the Royal Society of London, vol. i., 1655. Sir Robert Moray gave an account how fire heat was applied at the Mines at Liege. "A fire grate cradle was placed within a chimney 30 feet high—with a closed ash pit and a tube fitted below the fire communicating with different parts of the mine." It is probable, however, mines were then often ventilated by a fire suspended in the shaft to create a current. Dr. Desaguliers, in his Mechanical Philosophy, 1744, seems to claim the merit of having first applied fire draught to buildings in this country. He remarks, in his translation "Gauger" work referred to at page 49, that in 1723, for clearing the air of the House of Commons, foul-air grates were fixed, under his direction, in closets which he constructed above the house, to draw out the impure air. This appears to have been the first application to buildings of the principle of mining ventilation. It was an ingenious attempt to extract by forced ventilation the vitiated air from the ceiling;—before that, it is stated, the cold dense air descended through roof openings and annoyed persons below them.

From the Transactions of the Royal Society of London, it appears that in 1742 Dr. Richard Mead, F.R.S., brought before the Society another plan of applying fire heat to ventilation for ships and other purposes,—the invention of Mr. Samuel Sutton, brewer in London—which consisted of a tube or tubes of convenient size, closely fitted into a hole in the ash-pit of a furnace, or ship's coppers, with small branches connected with this tube, leading to various parts from which the air was to be extracted. It is obvious that this plan was merely another form of the application of that which was mentioned, seventy years before it, by Sir R. Moray.

Dr. Mead expressed himself in strong terms in favour of Mr. Sutton's plan, which he says was an "invention which does honour to our nation, and will in time be found of more public benefit than any discovery in mechanics which has been produced for these three hundred years." The difficulties which Mr. Sutton encountered to get his invention fairly tried form an episode from which subsequent inventors may gain knowledge. With all his perseverance, he, like many others, experienced disappointments.* His plans were in a few years, as respects ships, disregarded —and disused. The principle of operation was simple, but doubts were stated as to its safety from fire. The objections, however, which were chiefly of detail, brought against it, might have been overcome. It has been recorded by the author of Anson's disastrous voyage in 1741, that "our men were dying four, five, and six in a day, and out of a crew, but three months before of between 400 and 500 men, almost all of them in health and vigour, the lieutenant could not muster more than two quartermasters and six foremast men capable of working." It is also added, "Have the late invented plans and obvious methods of keeping our ships sweet and clean by a constant supply of fresh air"—(at that time there were several plans before the public)—"been considered with the candour and temper which the great benefits they promised ought naturally to have inspired?" "On the contrary, have not these salutary schemes been often treated with neglect and contempt?" "I impute this to hatred of all kinds of inventions, especially such as are projected by landsmen and persons residing on shore. For the *Centurion*, with above 400 men on board, sailed on her voyage without any other provision for ventilation than the ancient wind sails, which were found sometimes useless."

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* Extract from "Essay on the Ventilation of Ships," by the writer, printed in the Trans. of the R. S. Society of Arts, 1843.

The same idea, which Mr. Sutton entertained for ventilating ships, was revived in 1810 by Mr. Braithwaite. He mentions, in a work published by him, a method of drawing out air from the interior of ships by leading tubes of two inches diameter from the most remote parts of ships' holds to the galley fire. "These tubes can with the utmost facility be placed so as to prevent sparks or soot finding their way down, but which idea was so prevalent some years back, that they were discarded from the Navy."

Other methods of using air tubes have been successfully applied to the ventilation of ships and the airing of the timbers; and such tubes, both in timber and iron built ships, have been incorporated with advantage in their construction.

Mr. Sutton's idea, of ventilating by tubes, was taken up by Sir George Paul, Bart. in 1801, for the ventilating of hospitals and ships.* He considered that, in crowded wards of hospitals, channels for the escape of foul air were not sufficient to preserve a healthful respiration, unless the current was increased by rarefaction. He proposed an air-tight funnel to be made near the ceiling of the room, to convey the vitiated air to the ash-pit of a close stove or grate, to supply the air for combustion, and passed from thence into the chimney. This plan of carrying away noxious exhalations by tubes has now become common, even in domestic buildings,—and has of late years been strongly urged upon public notice, as an excellent method of extracting the inflammable gas and heavy airs in coal mines. * In 1835 Mr. John Murray, Lecturer on chemistry, Hull, in his evidence before a Select Committee of the House of Commons "on Accidents in Mines," recommended for their improved ventilation what he termed "a system of tubes; one connected with the roof, to carry the heated air (of the gallery) from the superior aërial stratum of the mine, and the other to bring down a current of heated air to replace that." "But in order to accelerate the ventilation, I should have the upper surface of the tube connected with the roof of the mine entering a brazier of ignited coke or charcoal. This, however, I would arm against occasional explosion by several folds of wire gauze. I would employ what is called Hancock's elastic Indian rubber tube, which costs about 1s. 6d. per yard. It is about one inch in diameter, and so very flexible that it could be easily bent in any direction and carried to any part of the works. The tube may be inserted in the wall of the downcast shaft, and be imbedded in the lower part of the floor of the mine—and by having a second pipe

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* Trans. Soc. of Arts, London.

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* The Parliamentary Report on Mines states that the respiration from increased atmospheric pressure and violent exercise was 1-10th, and that 14 cubic feet of air at least per minute for each person is necessary for respiration; as also that 2385 cubic feet of air was required per hour for a horse, or 43 cubic feet per minute.

to carry off the heated air and the lighter gas from roof, connected with a brazier of ignited coke, it would, I think, render it independent of a force-pump."

This method of ventilation was objected to by some scientific witnesses (amongst others by the late George Stephenson, C. E.)* from the difficulty of forcing air through pipes, the distance the air has to travel in some mines being more than thirty miles—and because the tubes would "be liable to be crushed by the thill arising and the roof coming down." The current that is passing in the downcast shaft must travel thirty miles or upwards before any heat is expended in the upcast shaft. Of that fact Mr. Murray says he was aware. Mr. Nicholas Wood, coal-viewer, states in his evidence that "it is well known that through small tubes you cannot force air to any great distance."† "I believe," he says, "there was an experiment made at the Carron iron-works by endeavouring to blow air through pipes between one of the furnaces and the other, and the effect was, that although a very considerable air-pump was employed, the resistance of the air was such as to counteract that, and very little current came from the pipes." Professor Leslie also mentioned this fact in his Diss. Encyc. Brit., and attributes it to the angular resistance and great friction.

This plan of ventilating mines does not appear to have found favour, but it has been repeatedly revived. At the exhibition of Inventions of the Society of Arts, London, 1858, Mr. J. W. Puall, Alston, Cumberland, exhibited what was termed a new invention for ventilating mines. The apparatus consists of a series of tubes built into the chimney above the furnace, with one end opening into the mine and the other into the upcast shaft. By this arrangement all the pure or impure air may be brought into contact with the rarefying gases without risk of accident. This is the revival of the plan of Mr. S. Sutton and others, of 120 years standing. Another plan, of a somewhat similar kind, entered in the Year Book of Facts 1856, has been also lately brought under public notice.

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* Rep. Sel. Com. Commons, "Accidents in Mines," 1835, page 106.

† Ibid. page 59.

Notwithstanding these suggestions and various others which will fall to be afterwards mentioned under the different heads of artificial ventilation, the plan first introduced for the ventilation of coal-pits still continues in use, and seems to be generally preferred,—namely, a furnace placed at the bottom of the upcast shaft, where there are two shafts, which should always be provided,—but where one large shaft only is used, it is divided by a brattice or partition, one half becoming the upcast shaft and the other the downcast; but when there is only one large shaft at a pit, from 11 to 15 feet diameter, it is often divided into three parts—one for the upcast, one for the down, and the third for pumping. The aërial current shown in the upcast and downcast shafts of mines, acted upon by the power of heat, uninterrupted by cross counteracting currents below, is a beautiful illustration how a movement of air is created. The fresh air being drawn downwards several hundred feet, passing through the various horizontal passages, workings, and chambers of the mine, to supply air for the workers and horses employed, is kept up at a certain rate of velocity—from 3 to 4 feet per second—till it arrives at the furnace at the bottom of the upcast shaft, when it increases from 8 to 10 feet per second, and thence passes upwards with the accumulated impurities of the mine into the atmosphere. The average temperature in the upcast shaft, taken half way between top and bottom, may be assumed at 90°.

Different opinions exist as to the best mode of venlating mines, and a vast amount of evidence has been led before Committees of the Houses of Parliament on the subject, having chiefly reference to accidents and the employment of children in mines. In one of these Reports (1842)* it is stated that the best mode of ventilating mines yet discovered "is by means of two shafts, sunk near each other, perhaps from 12 to 20 yards apart. A stream of air is made to descend one shaft, called the 'downcast shaft,' and a corresponding stream of air to ascend the other, called the 'upcast shaft.' The air is set in motion by means of a fire kindled at the bottom of the upcast shaft. A portion of the air in contact with the fire in this shaft undergoing the ordinary chemical change which takes place in atmospheric air in the process of combustion, is decomposed: the nitrogen is separated, and the oxygen, uniting with the carbon of the fuel, forms carbonic acid gas. Both these gases, as well as the portion of atmospheric air which remains undecomposed, being heated, are expanded, and occupy a proportionally larger space than the same weight of common atmospheric air, and in obedience to the laws of all fluid bodies are borne upwards;

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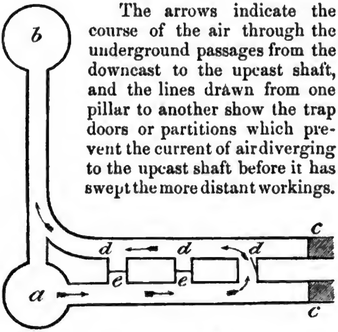
* Par. Rep., Children in Mines, 1842, p. 45.

consequently a strong current of air ascends the shaft; but if a free communication has been established below, between the two shafts, an equal current must at the same time necessarily descend the second shaft to fill up the partial vacuum which has been made in the first."* Here, then, a power is generated by the furnace capable of forcing a current of fresh air far beyond the distance to which any mine extends. The fire acting according to the degree of heat steadily maintained at the bottom of the upcast shaft. To whatever distance we may suppose the main-ways, side-ways, and all other works of the mine to be carried, communications may be made between them, and by means of doors properly placed the circulation of the air may be conducted and guided through them to any extent and in any direction.

Fig. 18 is a very simple diagram showing the principle of arrangement for ventilation without the intricacy attaching to a plan of all the ways in an extensive pit:—*a*, the downcast and *b* the upcast shaft; *cc*, the workings commenced. The advances are made from the bottom of the pit. Whatever be the distance, or whatever be the direction, they are always made in

Fig. 18.



The arrows indicate the course of the air through the underground passages from the downcast to the upcast shaft, and the lines drawn from one pillar to another show the trap doors or partitions which prevent the current of air diverging to the upcast shaft before it has swept the more distant workings.

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* Report by Commissioners on the Employment of Children in Mines, 1842, vol. xv., page 45.

double galleries or "bords" about six feet apart—one for air in its course from the downcast shaft *a*, and the other for its return to the upcast shaft *b*. When these have been pushed five yards onwards, a short traverse gallery or cross passage *d d* is made between them. Trap-doors or partitions *e e*, properly placed, direct the current of air as may be desired.

Mining ventilation at first view appears complex. Indeed, when the workings are extensive, and numerous partitions or stoppings required, it is difficult to be understood; but Dr. Birkbeck, in his evidence before Parliament, says that mines are ventilated "on the same principle as rooms, but with certain additional difficulties arising from the length of space to be ventilated (amounting in all its convolutions sometimes to 31 miles); still always requiring the same process,—that is to say, allowing heavier air to displace air that has been rendered lighter by some means or other, and thus in short producing motion in the shafts."* But although the principle of operation may be the same, yet he might have added that there is no analogy between houses and mines from the disastrous results which attend the neglect of ventilation in the latter. In truth, there is not one branch of ventilation of more importance, and which requires more knowledge and skill to be brought to bear on it, than coal-mining ventilation. In reality it is to carry a current of fresh air along with the workers, and to effect the perfect removal of impure air. But this impure air is rendered more dangerous by inflammable and other gases;

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* Rep. Select Com. Commons, "*Accidents in Mines*," p. 286, vol. v., 1835.—Evidence of G. Birkbeck, M. D.

and all that science has yet done has not been successful in preventing those deplorable accidents and loss of life in fiery mines of which we too often hear.

Although various mechanical means have been applied with different degrees of success to ventilate mines—such as the steam jet, pumps, fans, and other contrivances to be afterwards noticed—the general plan in this country is the furnace system; while in Belgium* and other coal districts on the continent artificial means such as fans and pumps are for the most part used,† "but in no instance producing 40,000 cubic feet per minute, and in most cases not half that amount." The Fourth Report of the Select Committee of the Commons on Accidents in Coal Mines, printed 26th June 1854, page 3, states, that having "well weighed the evidence which has been published, they are of opinion that imperfect ventilation is the cause of the numerous accidents from fire damp in this country." "That the Committee directed their attention to the various methods by which a supply of air might be obtained, with a view to determine their relative efficiency. Those which were brought under their notice may be stated under four heads,—viz. the Furnace system, the Steam Jet, Mechanical means, and Natural ventilation. They have had the results of various experiments laid before them, and have examined witnesses as to the merits of the different modes of ventilation above alluded to, and have to report that the preponderance of evidence is decidedly in favour of the Furnace—especially where shafts are deep."

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* Report of Com. Accidents in Coal Mines, 26th June 1854, p. 26.

† Ibid. Report, p. 3.

The arrival at this decision need excite no surprise, considering that the convenience of the furnace system, where coals are at command, would naturally enough lead to the preponderance of evidence in its favour;—but those who will consult the mass of evidence taken by Parliamentary Committees, and the Reports of Mining Inspectors, in 1835, 1842, 1844, 1849, 1854, &c., will find that in the opinion of many well competent to judge, the use of furnaces placed at the bottom of the upcast shafts has been attended with much risk, is no doubt the cause of many accidents, and hence is not so safe as artificial agency. It seems strange that it did not occur to these Committees, as the chief cause of death by accidents arises from the choke-damp—two-thirds of the deaths being caused by it,—that the furnace draught necessarily ceases, and becomes useless, from the flame being extinguished by the carbonic acid gas which is generated by the explosion,—whereas, by a well arranged process of mechanical agency, fresh air could be forced downwards, to neutralize, or to draw upwards the choke-damp at all times, even at and after the explosion; These furnaces are recommended to " be from about 4 feet to 6 feet long by about 10 or 11 feet broad, to present a great heating surface to the current; thin and low in the dome, so that the air may be brought as much as possible in contact with the fire, and so consume the coal, carrying off as little smoke as possible. That is the perfection of furnace-driving under ground, and it is important to make the air-ways large and copious."* But besides the furnace, the size and elevation of the shaft tends to regulate the velocity of the current.

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* Elliot's evidence, Par. Rep., 1849, p. 282, and 1854, p. 28; also Wood's evidence, 1835, p. 57.

To avoid the risk of passing the loaded returns through the furnace, in fiery mines, what is called a "dumb furnace" is used. The current of air is divided before reaching the upcast shaft. A smaller portion of the air drawn from the mine, instead of passing through the furnace passes over it, entering the shaft by a dumb-drift in an angular direction at some height above the fire, while the return air which is not inflammable supplies and passes through the furnace.* By this plan the risk of explosion is greatly avoided; still, in the opinion of some who gave evidence, the furnace at the bottom of the shaft can only be considered as a naked light, and may occasionally produce the ignition of the gas. Some mining engineers have advocated the placing the furnace at the top of the upcast, and to build a large chimney over it in order to avoid the risk of explosions in kindling the fire at the bottom of the shaft.† On this point the late George Stephenson, C. E., remarked, in his evidence before a Select Committee of the Commons in 1835, that "furnaces placed at the top are not so good as at the bottom; the deeper the pit, the more effect the furnace will have in causing ventilation" . . . . "an auxiliary furnace at top to one at bottom would have a very slight effect, compared with a very small addition of fire at the bottom."‡

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* Report, 1835, p. 40, and 1854, p. 26.

† See Report, 1835, p. 194.

‡ Do. 1835, p. 106; See also cause of Draught in Chimneys, page 7 of this work.

As so much valuable information on the ventilation of mines is given in the Parliamentary Reports, it is not the intention of the author to enter into details as to the various modes of working mines; but he will, in a subsequent portion of this work, notice the different motors which have been tried or proposed to avoid this danger. The importance of forced ventilation is fully brought out by the Reports of the Government Inspectors of Mines, 4th May 1854, embraced in the Report of the Select Committee of the House of Commons, 26th June 1854, in which they state "that an adequate artificial means of ventilation should be provided and constantly employed at every coal and iron-stone mine."*

GAS LIGHT USED IN MINES.

A most useful application to aid the labours of man is the introduction of gas light into the bowels of the earth, to enable miners to carry on their underground laborious employment. In all mines where no inflammable gases exist, this a simple process; and even where they do exist, the difficulty may be overcome. In a paper brought before the Institute of Civil Engineers in 1857–8 by Mr. A. Wright, it was shown that the expense of working mines in Cornwall and Devon was much less with gas than with candles, and that the health of the workmen was improved by it.

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* Select Com. Commons on Accidents in Mines—3d and 4th Reports, p. 44 and p. 72; and Suggestions, p. 8.

PART II.

DIFFERENT METHODS OF APPLYING FIRE HEAT TO THE VENTILATION OF BUILDINGS.

CHIMNEY DRAUGHT.

Of recent years the extension of the chimney draught has been applied, with various adaptations, on the principle adopted in mines, to the ventilation of buildings. The vitiated air being conveyed to the bottom of a vertical shaft or chimney, where a fire is kept burning, ascends with the rarefied current. Sometimes the extracting chimney stands isolated from the building (see Plate II. fig. 1) as at the Perth Penitentiary, &c., where the foul air from the cells, passing downwards, enters a horizontal under-ground tunnel, and is conveyed to the bottom of the chimney *C*, where a large fire *f* is kept burning. Another plan adopted is to place an iron smoke-pipe *b*, 8 to 15 inches in diameter, within a chimney *C*, or iron funnel of larger diameter (Plate II. figs. 2 and 3). This plan has been chiefly used (probably for convenience and economy in fuel) where a furnace *f* exists and is used for other purposes, at the basement of a building. The smoke-pipe *b* is sometimes led so far up the large chimney *C* (fig. 3), or it may be carried up the whole height (fig. 2) and escapes at the top. The heat from the inner pipe is supposed to be sufficient to rarefy the air within the large chimney, and to draw out the vitiated air from a building of several floors at *c c c*, and then to carry it upwards with the smoke into the atmosphere. This plan of ventila-

PLATE II. Page 133.

FIG. 1

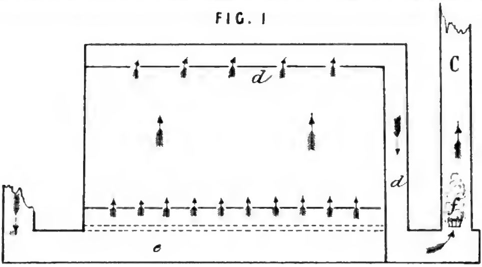


FIG. 2.

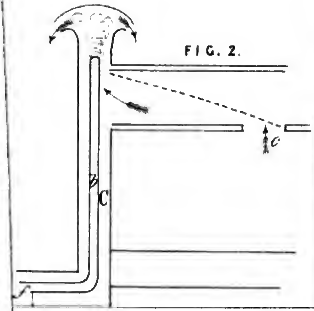


FIG. 3.

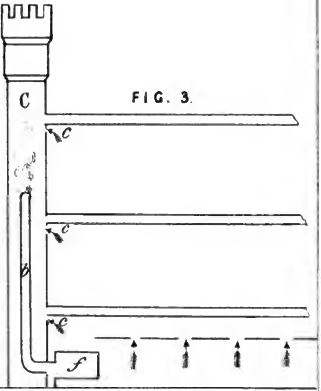
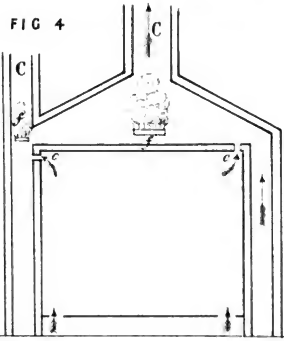


FIG 4



tion has been tried at several prisons—amongst others, at the Calton Hill, Edinburgh, the ventilating and warming of which, as also a part of the Perth Penitentiary, were done by Dr. D. B. Reid. This plan of ventilation has also been adopted at the new buildings of the Royal Infirmary, Edinburgh, and at some churches and other buildings in London and elsewhere.

There appears no certainty by those methods of ventilation by fire heat that the products of combustion may not find their way back into the rooms or corridors through the flues which connect them with the chimney,—the reflux of impure air being quite possible. When there is a strong fire with a high chimney, it will diminish the risk; but when the fire gets languid, the same cause that produces back-smoke may operate and give an uncertainty of action to this method of ventilation which must detract from its usefulness, and the quantity of fuel required, in order to be effective, is very great. Besides which, the inner smoke-pipe, exposed to damp soot and vapour, must soon lead to the decay of the pipe, and increase the risk of the escape of smoke from it into the large chimney, which may be termed the ventilating shaft, and from the latter it may find its way back into the apartments,—thus producing vitiated air, instead of extracting it.

Another method, perhaps simpler and more easily applied, consists in having a fire *f* placed under the roof of the building, with a chimney *C* above it (the foul air ascending with the hot current), carried as high as can conveniently be done, which in such a position, in general, cannot have much elevation. This arrangement for ventilation has been adopted at a number of buildings, amongst which may be named the Middlesex Hospital, Lunatic Asylum, and Detention House—the Model Prison, Pentonville, and other prisons—the Consumption Hospital, London, &c. At the Houses of Parliament this method of extracting the air is now applied under the direction of Mr. G. Gurney (1860). Fig. 4, Plate II. represents the process of a fire at the roof:—*f* is an iron grated bucket below the shaft. By the rarefaction, the foul air is drawn from different places to it, and receiving a great increase of temperature rises rapidly up the shaft *C*. In some cases the chimney *C* is placed at one side and the fire grate at *f*. This method is adopted at the Toxteth Hospital, Liverpool, &c. Fig. 1, Plate III. shows the manner in which the foul air is extracted at Pentonville Prison:—*f* is a furnace at the roof for summer ventilation, *h h* are smoke-flues. "During the winter months, when the fires are lighted in the apparatus below, *w w*, the smoke and disposable heat *h h* being thrown into the ventilating shaft *v v* above the upper cells, will generally be found sufficient to secure an effective ventilation." Fresh air flues *k k* convey the air to the apparatus *w w*, where it is warmed in winter, and from a main flue passes through small flues terminating "in a grating placed close under the arched ceiling of each cell."* It may well be doubted if the temperature of the smoke would be sufficient for the purpose of drawing the air upward from the floor of the cells, and it seems but an imperfect plan to be recommended.

* Prison Report, 1847, pp. 14, 17.

PLATE III. Page 135.

FIG. 1.

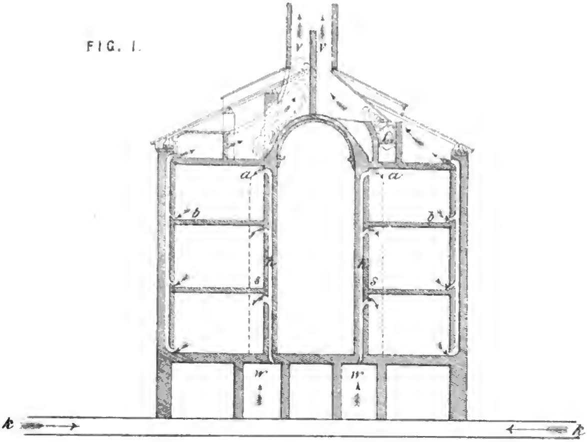


FIG. 2.

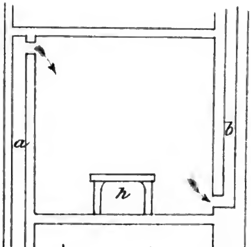
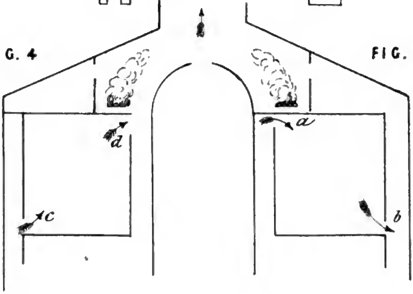


FIG. 4

FIG. 3.



At the Houses of Parliament various schemes have been tried. It has been shown that the first arrangement of ventilating by fire-heat was by Dr. Desaguliers in 1723. The same agent was also applied under the directions of Sir H. Davy in 1811, and by the Marquis of Chabannes in 1820.

After the destruction of the Houses of Parliament by fire in 1835, a select Committee of the House of Commons took evidence on the subject of ventilating, warming, lighting, and the transmission of sound, so that a systematic plan should be assured before commencing the new Parliamentary Buildings; and they recommended "that some if not all of Dr. D. B. Reid's suggested alterations should be submitted to experiment during the recess of Parliament, as the only means of accurately ascertaining the soundness of the principles stated in evidence, and their useful application." This led to the experimental House of Commons, in which Dr. Reid's ideas were carried into effect. He has published, in his work 1844, so full a description of his plan, that it is unnecessary to do more than refer to it. It was several years in operation. The ventilation was carried on by a powerful furnace *f*, (Plate II. fig. 1), 9 feet in diameter, placed at the bottom of a chimney *C*. The vitiated air ascending to the ceiling *d*, was drawn down by the shaft *d*, by the large fire at *f* encircling it, and ascending the extracting chimney *C* with the products of combustion from the fire. The cold or fresh air, regulated in temperature and moisture, entered a chamber below the floor by the conduit *e*. The object of this arrangement of bringing the foul air from the ceiling to the fire below was, that it was more convenient to have the furnace at the basement than at the roof, as by doing so, greater elevation could be given to the chimney. In this example, the rarefaction of the column of air is supposed to be sufficiently powerful to overcome the natural resistance which light fluids possess to go through heavier. But it must be obvious that great power of flame is necessary to draw down the vitiated air—and that the advantages of elevation of chimney are more than neutralized from the loss of power by friction and cessation of action when the combustion is languid. The ventilation by this method is entirely forced, whereas, by having the fire in the roof, it is partly assisted.

The retirement of Dr. D. B. Reid led to the introduction of a different arrangement for the ventilating and warming of the House of Lords from that of the Commons. In the House of Lords, Professor Faraday, in conjunction with Sir Charles Barry, adopted an ascending and descending system from the ceiling, which was divided into three compartments—two for the emission of the foul air, and one for the admission of fresh air.* From a description which was published in 1847 of the arrangement for warming, ventilating, and lighting the new House of Lords, it appears that the warming was produced by steam cockels, and the ventilation by means of Gurney's steam-jet at the roof, by means of which the impure air drawn from the House by one of the ceiling apertures was expelled into the atmosphere. The lighting was effected by Faraday's gas-burners. These things are mentioned, not from any intrinsic merit the system possessed, but to show the changes which have been adopted in this building. For in 1854, in the evidence given before the Committee of the House of Lords, we find Mr. John Leslie, when describing the plan then in use, stating that there was " a twenty-horse-power engine, which forces the air up as well as down into and out of the House, the foul air being pushed out by a fan as well as the cold air pushed in by a fan." * Mr. Leslie recommended " an ascending plan of ventilation, with a furnace above the ceiling."†

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* See Plate, Chap. V.,—Steam Jet.

As it has been shown (page 137) that Dr. D. B. Reid ventilated the House of Commons by fire-heat placed in the bottom of a shaft, but on the ascending principle, and as on his retirement Dr. Gurney has applied first the steam-jet and then fire-heat at the roof to extract the vitiated air, a description will be given to illustrate the process which has now been adopted. A few years brings about many changes. " The diffusion of air in the House without draughts being perceptible to any of the Peers, must be a convincing proof the success of the plan" was found to be not correct. Offensive currents were complained of, and the steam-jet was given up—it is said from the difficulty of keeping up the steam requisite, and the trouble and expense attending its use; and probably the noise it made formed some part of the objection to the system. In 1851 and 1852 Mr. G. Gurney was consulted about the ventilation and lighting of the Houses of Parliament, and received an appointment in regard to these matters from the Board of Works.

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* Q. 327, p. 31.

Q. 326, p. 30, and 376, p. 35.

He gave evidence before Committees of the Lords and Commons in 1854. Three Reports, with the evidence taken, were printed by the Commons, and one Report by the House of Lords. The third Report of the Commons is dated 24th July 1854, and from it the following extract is taken. "The House of Lords having communicated to this House the decision of their Committee, who recommended that the ventilation of the House of Lords and all the corridors and chambers adjoining, except the Library, shall be entrusted to Mr. Gurney,"—"that portion occupied by the House of Commons having been already temporarily confided to his superintendence, your Committee, satisfied with the experiment as far as it has gone, although necessarily as yet imperfectly carried out, thought it right to examine Mr. Gurney as to his willingness to undertake the ventilation of the whole Building, and as to the terms on which he would be content to do it."*

The result was that Mr. Gurney undertook the management of the whole ventilation for £1000 per annum.† Should Mr. Gurney continue to please both Houses, he is certainly fortunate, coming after so many able men who have attempted to do so and failed; and it is therefore not without interest to know the methods he has adopted. In the first Report to the Select Committee of the Commons in March 1854, p. 5, he presented to them a written report, and advises the following changes to be made:—

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* Third Report Select Com. House of Lords, 24th July 1854, p. 3, vol. ix.

† Third Report Commons, p. 2, July 21, 1854, vol. ix.

"1*st*, In regard to the House itself,—I advise that all the windows be made to open; 2*d*, That the present cumbrous and complicated mass of warming apparatus be removed, and that a more simple and manageable arrangement be made; 3*d*, That the system of ventilation be changed to the downward system; 4*th*, That all the lights in the Lobby and Division-rooms be insulated by smoke-flues, so that no heat from them or products of combustion should come into the House; also that the same arrangement be extended to the corridors, halls, and passages, and every other part of the House," &c.

Mr. Gurney states "that the House of Commons was not ventilated by him till 1854, when he was first called to report on it."* The description of how he proposes to effect the ventilation may be taken from his own evidence given to the Committee of the Lords in May 1854. In that evidence he differs from the opinions of many other scientific men. Thus: "*Question* 637—Your opinion is very strong that all the exhalations from the human body, and other impurities in the atmosphere, descend very soon?" *Answer*—"I think the most disagreeable do; I have no doubt of it."†

His ventilation is thus managed: "The change which I have made in the House of Commons is to admit fresh air freely to the lower parts of the House, and also above the ceiling, so that there is now a pneumatic balance between the external atmosphere and that of the House; consequently, whatever air is required in the House to maintain this balance comes freely in of itself. No power is used to drive it in. Any break of the balance by the escapage of the vitiated air is instantly and simultaneously restored."* . . . . "The fresh air comes partly through the floor and partly above. The floor is perforated full of holes under the haircloth; it is a cast-iron floor full of holes—the air is free to come through any portion of it." (Q. 644, p. 63.) He maintains that the air does not bring dust in with it. "The House is now like an inverted jar filled with warm air: nothing disturbs it; no cold affects it. A familiar instance is that of a lady's dress: their petticoats are open at the bottom to the open air, yet in the coldest weather they do not feel cold." The windows in the Commons are "opened so as to admit the free access of the external air on both sides to sweeten the House, but not opened when sitting."† After some evidence given, in which he states he had changed the opinion in his first report, he says—"Two fifths of the air is admitted at the floor, and three fifths from the ceiling through the sloping roof," and "the worst air in the Commons is now carried through the carpet at the centre of the floor about 30 feet above the basement." "A double operation takes place at the floor: fresh air is admitted, and foul air is drawn off."‡ "There is a special air-shaft reaching to the carpet—about 10 by 20 feet; through this the air is extracted; this descending shaft extends all the way from the floor of the House, communicating to the clock-tower. The clock-tower is made an upcast; so that the vitiated air is drawn up through the clock-tower after being drawn along the vaults passage, and down through this shaft communicating with the centre of the carpet," Q. 664. "What makes the air go out again at the bottom; is it done by furnace?" "Yes; the clock-tower is converted into an upcast," Q. 671.

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* Rep. Lords, May 1854, Q. 458, p. 42. † Ibid., Q. 637, p. 63.

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* Report, Lords, May 1854, Q. 642, p. 63.

† Ibid. 1854, Q. 646, 647, p. 64. ‡ Q. 657, 659, and 667.

The summary of Mr. Gurney's Report dated 17th June 1854,—from which it would seem to bear out Professor Faraday's remark when his opinion was asked "Have you examined the present system of lighting and ventilating the House of Lords?"* "I have not examined since the first arrangement by Sir Charles Barry. I have preferred keeping myself out of a knowledge of the facts—thinking the matter was already too much complicated." From Mr. Gurney's evidence it appears that the term he has adopted to describe it is—"a pneumatic balance between the open air and the house."† By this plan part of the vitiated air is extracted from above and part from below, and an agent is employed to extract the air or accelerate the current. The air is also warmed, as on Dr. Reid's system, in a chamber of preparation, and the gas-burners are entirely separated from the apartments which they illuminate.

Upon a recent examination, during the spring session of the present year, of the Houses of Parliament, which were then under Mr. Gurney's management, large coke fires were burning in iron grates under the roof of the building, for extracting the vitiated air from the foul-air flues. These fires consumed at the rate of six bushels of coke or cinders per hour to give the required heat, and were kept strongly burning during the whole sittings of the Houses. The quantity of fuel required does not well agree with Mr. Gurney's evidence in 1854, when he stated that he "could do with a small fire."* The foul air drawn from the horizontal flues above and below passes under and around the charcoal fires into a vertical shaft, and from thence into the atmosphere. The fumes from the fuel must be most offensive, if not injurious to those who attend the fires. The products of combustion from the gas-burners, separated from the Commons House by a glass partition (the plan Mr. Gurney proposed for both Houses), are led by tubes placed above the burners into the main ventilation shafts. Mr. Gurney, in his evidence before the Peers, at first proposed for that House to use "ventilated ring-burners" placed at five feet from the ceiling; but he states that he gives a preference over all other modes to the plan of "lighting through the ceiling in a manner similar to that adopted in the House of Commons."†

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* Report, Lords, 1854, Q. 910, p. 92.

† App. D., Report, Lords, 17th June 1854.

In the warming of the House, so essential in winter, Mr. Gurney seems to carry very much out the plans of Dr. Reid in moistening and warming the air; but instead of using hot-water pipes, steam apparatus upon a new construction has been substituted by him. What he terms "steam batteries" Fig. 19, are used,

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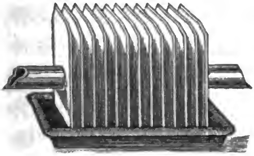
* Report, Lords, 1854, Q. 472, p. 43.

† Q. 927. A very ingenious plan of lighting gas-burners at the roof by means of a galvanic battery has recently been introduced.

Fig. 19.



which consist of metal plates 9 inches square, placed vertically about 2 inches apart from each other, forming a block 30 inches long. These plates are heated by passing a steam-pipe through them. The number of these batteries is increased according to the extent of heating required. At the House of Commons a great number of these batteries, heated by the same steam-pipe, are placed above one another in the vault below the House, exposing a considerable extent of heating surface, there being about 24 plates in each battery. The object of this complicated invention is to avoid the risk of the plates themselves reaching the same degree of heat as the steam-pipe which heats the plates. The air is raised to a temperature of above 64°. In cooling the batteries, wet woollen cloths of non-conducting substance are laid upon them, or they are covered by the person in attendance, which is a troublesome process; but Mr. Gurney states that the surface-batteries can be cooled by ice. In the House of Lords the batteries are placed on the floor of a vault in four parallel ranges, all connected for evaporation together, the small steam-pipe passing through each row being supplied from steam-pipes over it, bringing the steam from the boiler.

This mode of heating does not seem to present sufficient advantages to lead to its being preferred to hot-water pipes;—it is both more expensive and complicated; it requires a great many batteries to bring up the temperature, and each of these batteries will cost several pounds exclusive of their erection. It does not admit of the heat being turned off and easily reduced when cooling is required. A close iron stove on a similar plan, with radiating plates, has been lately introduced.* The plan for the filtration of the air by Dr. Reid is still continued,—namely, of passing the air through porous cloths, at the apertures at which the fresh air is admitted, which at the House of Commons are at the ground-floor of the inner court. A simple plan of imparting moisture to the air by means of spray-jets has been adopted. A small jet of water strikes on a disk, which creates a soft shower falling upon the porous cloths or upon the floor.

This downward system was first applied to the House of Lords, where it appears to have been condemned, and is now converted by Mr. Gurney into a movement of the air upward and downward at the same time, and also opening windows This led to the following remark by the Hon. E. P. Bouverie, in his examination before the Lords Committee in the year 1854:—*Question* 762, p. 75—"Do you think that Mr. Gurney's improvement in the ventilation of the House is mainly attributable to the windows being open?" *Answer*—"I have heard it said that the result of our spending £200,000 in the ventilation of the House of Commons has been to prove that the best way of ventilating a room is by opening the windows." Notwithstanding that Mr. Gurney may be deemed high authority from his scientific attainments and ingenious inventions, yet it will not be an easy matter for him to reverse the law of nature that light fluids ascend, and that therefore the air from human respiration, as it escapes from the lungs at a temperature of 98°, should be extracted upwards and not downwards. The evidence which was produced in Chapter II. p. 79, is so conclusive on this head, that no sophistry can rebut it. There may be indeed a great deal of plausible reasoning brought to bear upon the withdrawing of the vitiated air through openings near the floor—such as, it has been said, that with upward ventilation the vitiated air is liable by check or condensation to be thrown down and mixed with the air which is already partly unfitted for respiration, whereas if the vitiated air is drawn downwards, there will be a pure atmosphere above. As the carrying out the latter position obviously implies the agency of forced ventilation—so, if the same agency is applied above, the impure warm current ascending will require much less power to assist its expulsion. Many years ago Dr. D. B. Reid, in a letter in reference to the arrangements for ventilating the House of Commons, seems to have been strongly in favour of the air being "made to descend from the ceiling and be removed from the floor." On this point the Surveyor-General of Prisons remarks, in his description of Pentonville Prison,* (Plate III. figs. 1 and 3), "Objections may be urged against the principle of making the point of entry of fresh air at the top of cells (*a*) and extracting the foul air from a lower level (*b*); and as an abstract matter of science it may possibly be a question whether this order should not be reversed." In fact it has been reversed in new erections, as shown in the same plate (fig. 4, *c*, *d*), but it cannot be altered in buildings already constructed. The Report goes on to state, "that the ascending principle of the ventilation of the entire prison is preserved, and that the extraction of foul air from the cells is partly to be referred to the superior altitude of the extracting flues and shaft, which are in and above the roof. If the foul air were required to pass downwards below the floor of the cells into flues situated in the basement, a power must be maintained in constant operation to overcome the tendency of air at a higher temperature to remain at a higher level." It thus appears that doubts existed as to the soundness of the principle when it was adopted. This plan of downward ventilation was tried at a prison lately erected, where no provision was made for extraction of the vitiated air, and the cold air came in at the lower opening, as might be expected from the facts stated in a former chapter, instead of the foul air going out. Taking Dr. Reid's opinions from his work,* he seems to consider that a descending movement of the air is chiefly applicable "in cases of forced ventilation under peculiar circumstances"—and that "the ascending movement is the natural system." It may be easily surmised that the plan of extracting the vitiated air through apertures below has obtained supporters from those who may have formed a judgment of ascending ventilation from examples acting imperfectly,—while the downward system is much more imperfect, and adds to its imperfections pernicious influences, because if fresh air be admitted into rooms at the ceiling, it must pass through air which has already been respired. As for removing so much air up and so much down—the one current may counteract the other, and the whole plan in all probability prove ineffective, and might have done so ere this time in the House of Commons, were it not under Mr. Gurney's direction. The question may be asked, when an offensive smell arises in a room, is it not diffused as it ascends? It would require a strong draught to take it downwards. Even take air impregnated with a large per-centage of carbonic acid, mixed with the most pungent odour, and the nostrils will soon detect the ascensional movement. And according to Mr. Gurney's idea of drawing the air downwards through the floor, it will be remarkable if he can draw effluvia downwards, unless a powerful extracting agent is employed to create the current and to overcome the friction and the laws of specific gravity; and accordingly he makes use of the Clock-Tower as an upcast shaft for both Houses.*

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* These stoves are, however, liable to the faults which appertain to all close stoves, where the fire is placed within the metal,—namely, the liability that the fumes of combustion are mixed with the air to be respired.

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* Report, p. 15, 1847.

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* Reid's Illustrations, p. 85, 1844.

It may thus be seen that one of the chief difficulties which arise from the practice of ventilation at the present time emanates from the uncertainty in almost every point which appertains to it. It has been shown (Chap. II. pp. 78–9) the difference of opinion that appertains to the process of extracting the air upwards or downwards, and that the preponderance of scientific men was in favour of the former. We will now proceed, as was intended, to illustrate the downward process by a few examples in which fire-heat has been used as the extracting power.

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* Report, Lords, Appendix D., June 1854.

As Guy's Hospital, London, has been considered one of the most prominent examples of the descending system, a short notice of it will serve to explain the process. The portion of the building to which it applies consists of a central compartment with wings of four floors in height, extending to a distance of 200 feet from the centre on either side. Each angle of the central portion is carried up as a tower, and is finished with an open lantern and cupola, which serve as fresh-air inlets to the building. By means of vanes, shields within the lanterns are made to present their open sides to the wind. Between the lanterns of the two central towers and the basement there are large air-shafts, and from the bottom of these the air is conveyed in channels to the extreme end of each wing, each tower supplying its own side exclusively. The fresh air is warmed at the basement, and from thence is carried upwards in flues constructed in the walls to the different wards. Plate III. fig. 2, shows a section of a room where *a* is the inlet above and *b* the outlet below. The area of the flues is supposed equal to give a supply of 60 feet for each patient.

The arrangements for extracting the vitiated air are much on the same scale as those that supply the fresh air. Flues (*b*) constructed in the walls convey the vitiated air from the basement of the rooms upwards into a horizontal channel at the roof, having a sectional area for each wing of 70 feet. A rarefying apparatus is placed at the roof to insure an active summer ventilation; the vitiated-air channels from each wing terminate in a central shaft having an area of 200 feet, equal to two of the fresh-air inlets. The flue apertures for the exit of the vitiated air are placed, strange to say, with their tops nearly level with the heads of the patients while in bed, and close by its side. Fire-places (*h*) are also provided in the rooms. Besides the vitiated air from the wards, the central shaft receives the vaporized air from the drying closets, the smoke from the steam boiler, warming apparatus, and all the fire-places in the establishment.

The result of the examination made by the author of the ventilating system in this building was, that it was far from satisfactory. The plan aims at too much, and hence the complication and difficulty in management arise. The whole of the fire-places leading into a common flue is attended with much practical inconvenience, as must be sufficiently obvious. The reversing the natural law, and making the fresh air enter above, is always attended with uncertainty in the working of it, for it obviously requires powerful mechanical agency to create a current sufficiently strong to carry away the vitiated products; while the instant the mechanical agency ceases, the ventilating current is checked also, or it becomes reversed, and the fresh air comes in at the aperture where the foul air is intended to pass out.

At the new Surgical Hospital of the Royal Infirmary at Edinburgh, built several years ago, a plan of forced ventilation was adopted somewhat similar to that in Guy's Hospital, the vitiated air being withdrawn in the different wards at the floor. Along the basement of the walls there are placed boxes or cases perforated with numerous small circular holes. The heads of the iron bedsteads of the patients are placed close to these air-boxes, which are about 18 inches deep and 12 inches broad. A flue formed in the wall about the same size opens into each case. These flues convey the foul air from the wards into a large main central shaft or chimney, which is carried up with a square head a little above the roof of the building for the discharge of the foul air. Into this chimney an iron pipe is placed (Plate II. fig. 3), which carries up the smoke from the furnaces at the basement. It was supposed that the heat from the pipe in the shaft would rarefy the air within it sufficiently to draw out the vitiated air from the wards. The passages are warmed by hot air from gratings in the floor, and the wards, each containing from six to ten beds, by open fires. The ceilings of the passages were lowered, and the space above formed into air-trunks having apertures to admit the warm air into them; and from these air trunks there were inlets at the upper part of the wards (the ceilings being high), which admitted the air into them. From an examination of these wards in 1860, it was found that the inlets from the air-trunks were closed up, and the scheme of extracting the air at the basement abandoned. The medical authorities had inlets made in the middle of the wards for the admission of fresh air, and apertures in the ceiling for the escape of the impure air. This shows the inutility of the complicated and expensive arrangements first prepared.*

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* It was stated by one of the Surgical Lecturers, that from the first the heat in the shaft had never been sufficient to produce an adequate current to draw the foul air from the base-

It is unnecessary here to enlarge more upon the ascending movement by fire-heat, as figs. 2, 3, 4, Plate II., and fig. 4, Plate III., sufficiently illustrate the principle, which will be afterwards referred to.

SCHOOL-ROOMS.

It is to be regretted that forced ventilation either by means of fire-heat or other agency has not been more applied to schools than it has been, as there are few buildings where an effective process is more important. In the numerous school-rooms examined by the author, no provision whatever exists beyond windows, and even these are often placed so as to render their ventilating power less effective than it might be—the windows being too low, and the ceilings of the rooms not sufficiently high. So much has been said at pages 43 and 44 of this work as to what could be done in renovating the air of school-rooms, factories, workshops, &c. by means of a proper construction and arrangement of windows, that it is unnecessary now to say more on the subject. These opinions will be found to be corroborated by the Report of a Select Committee of the Lords on

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ment of the wards; but even supposing that it had been so, the plan was objectionable, because, as the late Professor Sir George Ballingall, M.D., remarks in his "Observations on Hospitals" (1851), "the plan of bringing in fresh air from above and abstracting the vitiated air below appears erroneous in principle, in as much as the air being brought down and inspired by the patient, will again be thrown out or expired at an elevated temperature." The inlets for the warm air from the passages must have been equally erroneous in principle, for whatever impure air existed there, must have been at once discharged into the wards to be inhaled by the patients.

the Houses of Parliament in 1859.* In school-rooms and other occupied places, the cubical contents should correspond with the number of inmates, allowing not less than 10 cubic feet of air for each person (see page 69), giving a proportional height to the room; the windows to be nearly as high as the ceiling, and to open with facility. When windows exist at opposite sides of a room, it is easy to pass a current of air through it to renovate the interior atmosphere without internal disturbance, thus affording a simple means of renovation. In some instances, glass ventilators to open and shut have been used with advantage. In buildings where windows cannot be placed at opposite sides of class-rooms, recourse should be had to forced ventilation. One apparatus can easily be made to extract the vitiated air from several rooms. Fig. 4, Plate II. will serve to illustrate this principle. Plans have been recommended by some parties for ventilating school-rooms and other places by what is termed a "double-current ventilator" placed at the ceilings of rooms, the fresh air entering there—such as noticed at page 85. The advantages and disadvantages of ventilators of this kind, such as Watson's, Mackinnel's, and Muir's, are pointed out in the Report of the Parliamentary "Commission for improving the sanitary condition of Barracks and Hospitals," p. 69, 1861—where it is also stated that Sherringham's air inlet has been found convenient and useful.†

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* Minutes of Evidence—Gurney—page 64, Question 645.

† Since the preceding was written, an improvement has been made in window ventilation by Mr. William Cooke, C. E., London, who has obtained a patent for regulating the introduction of air into rooms by means of wire gauze in two or more folds, of any size or width. The gauze is attached to the top sash of the window, by which draughts are diminished and the admission of dust is prevented.

PART III.

FORCED VENTILATION BY MEANS OF HEAT FROM GAS.

The many advantages which society has obtained by the general application of carburetted hydrogen gas to lighting purposes cannot be overrated.* As respects heating purposes, its range as yet has been very limited. The expense † and other causes have operated against its general use. The report of the Commissioners appointed to inquire into the warming and ventilation of buildings was not very favourable to it. "By the use of gas or coke there is no smoke; but with respect to the former, the results of all our inquiries prove it to be too expensive for heating purposes in cities or towns remote from coal districts." Report 1857, page 98.

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* According to the authority of Dr. E. Lankester, "coal gas consists of about 40 per cent. of hydrogen, nearly the same amount of light carburetted hydrogen, from 5 to 10 per cent. of hydrocarbons with variable proportions of carbonic acid and carbonic oxide, sulphuretted hydrogen," &c. Composed thus of poisonous gases, its inhalation is followed by insensibility and death. When only 7 to 12 per cent. is present in the air it will kill in a short time small animals, and produces on man a great lowering of the vital powers. Besides, coal-gas other lighting agents, such as oil, tallow, stearic acid, wax, camphine, &c., from the same amount of light in burning, take from the air its oxygen and vitiate it in different degrees—(*see* page 22, *ante.*) "Two common gas burners" it is found, "consuming 10 cubic feet of gas per hour, will consume 12⅝ cubic feet of oxygen, produce 6½ cubic feet of carbonic acid, and vitiate 2146 cubic feet of air—having a heating power in cubic feet of air raised 10 degrees, 32½."

The use of common gas requires care, because a mixture of 1 part with 6 to 7 of air, is explosive, exerting a force equal to 30 atmospheres. A gas called water-gas has been proposed for lighting, which is too dangerous to be used. The oxy-hydrogen or Drummond light and the electric light have highly illuminating powers, and are said not to vitiate the air in burning; but at the present time they are too troublesome and expensive for ordinary use.

† The present price of gas in Edinburgh is 4s. 10d. per 1000 cubic feet; but the price varies much in different places.

The author of this work, several years ago, brought the subject of heating by gas before the Royal Scottish Society of Arts, illustrated by a gas-stove of his invention, showing how the products of combustion might be removed and air supplied not taken from the room; but the report of a committee at the time held out little encouragement for the employment of gas as a heating medium. No doubt, by the introduction of the Bunsen burner the heat can be more easily concentrated at one point, which makes this heat on a limited scale useful for many purposes. So far, however, as the warming of apartments with gas is concerned, as regards the amount of caloric produced it is the same from a cubic foot of gas whether it is burned as a light or in a stove, or in any other manner. The numerous contrivances, therefore, of gas-stoves, so far as giving increased heat is in question, are based upon a fallacy, though they may sometimes be used for the convenience of bringing heat to one point; but the mere inclosing the burner in an iron case, instead of increasing, tends to diminish the heating power of the gas consumed.

GAS AS A VENTILATING AGENT.

When considering the utility of this agent, salubrity must not be overlooked, although convenience will sometimes lead to its value being overrated. Much heat can be obtained from it only by a large consumption, and consequently at considerable expense; but a greater evil arises, for the heat cannot be obtained in apartments except by consuming the oxygen of the atmosphere and by the generation of carbonic acid gas.* The vitiated products therefore require to be removed as they are produced, for if they be permitted to mix with the air required for respiration they must tend to increase the interior atmospheric impurity. No agent employed for ventilation should produce this effect. When the products escape into the external atmosphere they will be checked unless proper precautions are taken, and will return to be re-inhaled. To breathe such an atmosphere must be highly injurious; and thus various contrivances have been made use of to prevent the reflux of the carbonic acid and other hurtful gases into apartments. From the flame of gas in an apartment considerable heat is evolved in the combustion; but even when air outlets are made above them they do not appear in general to be sufficient to carry off the foul vapours freely into the atmosphere; hence these, combined with the exhalations from the people, are returned upon them; and to this is added the inconvenience arising from the parched air produced. This imperfect operation of ventilation, as shown by the heat, closeness, and impure state of the air, may be often experienced in the galleries of churches, public halls, theatres, and other buildings, and (though to a less extent) in the upper part of houses; the same evil will be found more or less to exist in every apartment where much gas is consumed.

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* The presence of sulphur contained in coal-gas, absorbing oxygen from the air and becoming sulphurous acid, is pernicious. The amount of sulphur in 100 cubic feet of coal-gas will give from 30 to 50 grains of sulphurous acid. It produces a corrosive effect, which combined with its dryness has been found injurious in libraries, to goods in warehouses, and to plants in conservatories. The necessity, therefore, for the removal of the fumes of the gas is evident.

In ordinary apartments the hot vitiated air, composed of carbonic acid and moisture from gas or lamps, rises directly to the ceiling, and then, as it is displaced by warmer air, it becomes mixed with streams of colder air from doors and windows as it passes to an open fire. Thus above the level of the discharge, the air may be noxious and charged with products of combustion (the presence of which is easily detected by the carbonometer*), while the atmosphere below will be less impure.

VENTILATING BY THE SUN-LIGHT BURNERS.

In order, if possible, to obviate these defects, a contrivance has been introduced called the sun-light burner, which combines the lighting and ventilating of apartments. It consists of a number of jets or bat-wing burners arranged in rings one above another, or in different forms, which are placed at the ceilings of rooms, under a vertical ascending shaft or chimney. As many burners are made use of as may be sufficient to light the apartment and also to promote its ventilation.

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* A small glass bulbous tube, containing some test of carbonic acid, as lime water. See page 11, *ante*.

Fig. 20.

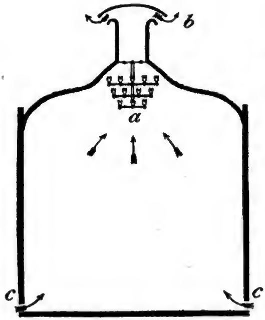

Fig. 20 is a diagram exhibiting the position of the sun-burner as a ventilator and illuminator placed at the ceiling of a hall or church : *a* is the "sun-burner," *b* egress for vitiated air, *c* inlet for fresh air into the apartment.

As examples, it may be stated that in one large hall there were placed three sun-burners. One in the centre, larger than the two others, had 460 jets arranged in about 30 small circular rosettes; the two other sun-burners had 250 lights in each. The quantity of gas consumed was very great; the current was considerable. Besides the sun-burners, side lights were required for the lighting of the room. In another hall of lesser dimensions there were three sun-burners used; the centre had nine rosettes containing 135 burners, and the others had five rosettes, with 60 burners in each,—or a total of 255 burners, quite sufficient to give a blaze of light in the room and a good ascending current. The quantity of gas consumed was necessarily very large. In smaller halls about 80 batwing burners have been applied with different degrees of success—but of course the illuminating power must be regulated by the area of the room. From the position of the sun-burner in a large apartment, especially if high, a much greater consumption of gas is required to produce the same light than where the burners are otherwise arranged;—and as regards the ventilating effect, even a very large consumption of gas is insufficient to effect a rapid ascending current. Hence, unless there is combined with this mode of ventilation a high ascending shaft, and means taken to prevent a direct down-draught at the roof-escape, the products of the combustion from the gas may re-enter the room, and when the wind is high the lights are affected by it. While, therefore, the expense of maintaining a sufficiency of heat for ventilation in this manner is considerable, the process after all is but an imperfect one.

In various applications of this method to ventilation it becomes more expensive, and the quantity of gas consumed must necessarily be great, from the necessity of using the sun-burners all the year round. In some churches or halls, two or more of these sun-burners may be seen used in summer entirely for ventilation, as it is as much wanted then as in winter; thus the same amount of gas is consumed to produce an upward current as when the light is required. In ventilating buildings with gas flame at the roof, care is required to guard against the risk of fire. The burners are sometimes lighted from the roof and sometimes from below with a long rod. The mode of lighting by means of a galvanic battery and wires is noticed at page 143, *ante*.

BURNERS ABOVE GLAZED CEILINGS—IMPROVED GAS-LIGHTS.

Various contrivances have been adopted to prevent the reflux into apartments of the impure gases evolved in the combustion of gas, but most of these impede light as well as the strength of the current or ascensional force which has been produced by the rarefaction of the air. These include—(1) Arranging the light without the apartment, the light entering it as at a window; (2) The light being in the apartment, but supplied with air from without, while it has no communication with the air of the apartment; (3) The light being supplied with air from the apartment which it illuminates, and the products of combustion being conveyed into an appropriate channel without communicating the vitiated air to the apartment.

The first method is placing the gas-burners or naked lights above a glass ceiling, with such obscuration of it as to conceal as much as possible the site of the lights. The third plan is most usually adopted, and in various ways the rings of the burners are placed in glass globes at the ceilings of rooms, having tubes above the burners to carry away the fumes from the gas; or side-lights and oxydators may be used, and the fumes conveyed from the burners by tubes into a chimney.

No plan, however, which does not separate entirely the flame of the gas from the apartment can prevent the risk of the mephitic air entering the apartment; and hence it should not require the air of the rooms to carry on the combustion, or in other words, the flame ought to be entirely separated from the room. The attainment of this object has long engaged the attention of scientific men such as Faraday, Reid, Gurney, &c.; the object being to improve the illuminating power and to throw off the heat and products of combustion from the burner. The great amount of carbonic acid gas produced by the flame is easily tested by means of the carbonometer.

In some of these contrivances the air is brought from without to the burner itself,—the fresh air supplies the gas flame, and having parted with its oxygen, the carbonic acid and other deleterious products are conveyed downwards by a tube, or they may be drawn off by an extracting apparatus into the atmosphere. These products, however, from the heat produced by the combustion, can be more quickly withdrawn by direct ascent than by any other mode, unless the lights are placed without the apartment.

Fig. 21.

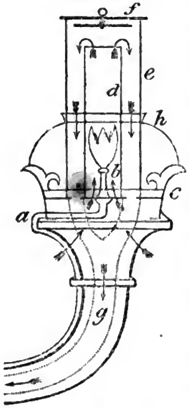

Fig. 21 shows a section of Faraday's burner: *a* is the gas pipe leading to the burner; *b* the burner to which fresh air enters; *c* glass-holder having an opening into mouth-piece connected with a metallic tube; *d* ordinary glass chimney; *e* outer cylinder of glass closed at top *f* with a plate of mica; *g* metallic tube to carry off the products of combustion.

From the various experiments which were tried in the Houses of Parliament, and from the report of Committees in 1854,* in the Commons the gas burners have been separated from the House by means of an intermediate glass ceiling, and are not applied to extract the impure air. In the House of Lords† Mr. Gurney proposed "four pendent lights thoroughly ventilated by means of tubes, and of sufficient power to light the business part of the House" to avoid any change in the ceiling; but "he preferred the plan of the other House." The evidence led goes to show that, as respects the combustion of gas in rooms for ventilation, the products should be entirely removed from the apartment; and if the heat evolved in its combustion be entirely removed from the room it ceases to act as an extractive agent to withdraw (unless by some special arrangement) the vitiated air; the fact being that the gas, applied as in the "Sun-ventilator," is merely to produce, combined with lighting, an artificial current at the roof; and various contrivances, to be afterwards described, for aiding the expulsion of impure air, avoid the closeness, heat, and the liability of the products of gas-combustion mixing with the air of the apartments.

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* Report, Commons, March 1854.

† Report, Lords, July 1854, vol. ix. pages 7 and 60.

Although gas is in many respects defective as an extractive agent, still its convenience and requirements in public buildings for lighting make its application for ventilation purposes more general than it otherwise would be, and therefore it becomes important to obviate as much as possible the injurious effects arising from its use. How long ventilation by gas will continue in favour experience will show, but it is not likely to do so unless two objections are removed—first, the expense of consumption of the gas; and second, the atmospheric vitiation which it produces. Unless the latter defect is removed, which cannot easily be done, ventilation, as well as heating with gas, will continue to be imperfect. It is little better than vitiating the air which is to be inhaled. There are, strange to say at the present day, to be seen churches and halls in which the doors are shut before the people assemble, and the gas-burners being lighted for many hours, the temperature is raised by the large combustion of gas destroying the vital principle of the air, its oxygen; and the air being confined in the building is inhaled by the people when they enter, and their lungs filled with a pernicious atmosphere. It is surprising to see such things, when it is said, to use the well known phrase of Lord Brougham, that "the schoolmaster is abroad." In other buildings, gas is burned in close stoves, but the great fault of these is that the products of combustion are not thoroughly removed.* In one of these stoves the burners were small holes in a tubular ring inclosed in a case, this case being placed within another case, from which a vertical funnel conveyed the heated air into the room. All stoves are dangerous in which the products of combustion are allowed to mingle with the air of the apartment. Is it not, therefore, highly improper for any one having the charge of others to let them be injured by such contrivances? †

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* This subject has not escaped the notice of Miss Nightingale, who in her "Notes on Nursing," under the head of "Ventilation and Warming," points out the absurdity and error of airing a sick room from a passage "through the door, near to which were two gas lights, each of which consumes as much air as eleven men."—Page 12.

† A plan is noticed at page 115 of this work, showing how the exhaled air may be withdrawn from a room by the combustion of gas. In summer, gas burnt in the chimney could be easily applied to aid ventilation.

CHAPTER IV.

FORCED VENTILATION BY HEATED METALLIC SURFACES AND BY THE STEAM-JET.

PART I.

VENTILATION WITH HOT WATER.

Having shown some of the various applications of fire-heat and gas to ventilation, an account will now be given how heat in other forms may be usefully applied to attain the same object. Hot water will first be commenced with, because water must first be heated before it is converted into steam; and if the same ventilating effect can be obtained with hot water as with steam, there is less trouble and risk attending its use;—and the obvious advantages of water as a heating medium are, that the heat is retained in the pipes, whereas steam-pipes are not hot but when the steam is in them.* It may, however, be stated, that unless it had been discovered experimentally that by the patent screw-joint invention of Mr. A. M. Perkins of London, water could be heated in tubes with perfect safety under pressure,†—and that, at 212 , water in the liquid state, when atmospheric air was excluded, only expanded 5 per cent.* or 5 gallons per 100 gallons, nothing could have been made of this application of heat to the purposes of ventilation, as large cast-iron pipes or cases were not at all suited for such a purpose. The writer of this work was long ago impressed with the advantages that the system of high-temperature tubes presented for ventilation,—seeing the danger that attended placing open fires of any kind at the roofs of buildings to extract vitiated air. It occurred to him that if an artificial heat to a high degree were produced in a small accessible chamber at the roof of a building with hot-water pipes heated by a fire placed at the basement of the building, there would not be the same objections to this as to the methods which have been alluded to. Various experiments were first tried with steam heat to ascertain the temperature which could be obtained, and in 1842–3, in a paper to which allusion has been made, brought before the Society of Arts, which is printed in the Transactions of the Society, the writer pointed out the safety of the application of hot water and steam as extractive agents to obtain forced ventilation.†

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* "Knowing steam to be 1800 times lighter than water, it may easily be conceived how readily a small stream of water may be kept in constant circulating motion;—and when combined with its power of absorbing heat, it is not surprising that it should extend through considerable length of pipe before it cooled so as to be inefficient."—Richardson, p. 27.

† The joint invented by Mr. Perkins gives great security to the apparatus, and is capable of sustaining a pressure equal to the tubes themselves. It is now extensively used in several other departments of engineering.

R. RITCHIE'S HOT-WATER VENTILATOR.

After various experiments he succeeded in applying the hot-water apparatus or artificial concentrated heat at the roof of the Circuit Court-House in Glasgow in 1843, and shortly afterwards at the Police Buildings in Edinburgh. It was found that, by this means, not only could a sufficiently powerful extracting force for the withdrawal of vitiated air from buildings be obtained, but that the plan was free from all risk of fire, and attended with much less trouble in the management than any other plan. It required no fire to be kindled at the roof, and was noiseless in its operation, nor was there any risk from it of the products of combustion finding their way into the apartment below, which might happen both with fire and with gas. The expense of the great consumption of gas was avoided, and there was little trouble in lighting it; neither was there the risk of the escape of gas nor the liability of burners being affected by strong currents of wind. For the method of ventilating with hot water the writer received a high premium from the Royal Scottish Society of Arts, and he has successfully applied this system to several buildings in Scotland. Its application in 1856 to another Court-House in Glasgow proves that the advantages of it are now becoming more appreciated from its recognised simplicity and certainty of action, and the little trouble in management, and (the fire being placed at the basement) its entire freedom from the risk of fire, which cannot be the case when either gas or coal fires are lighted at the roof. The following letter shows the opinion of the Architects on this mode of the ventilation of buildings with hot water:—

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* Water when heated from forty degrees to two hundred and twelve degrees, expands about five per cent., and as it is known that it requires 28,000 lbs. to the square inch to compress water five per cent., hence the necessity of allowing sufficient expansion for the water.—Richardson p. 27.

† Reprint of his paper, from Transactions (1842), pages 15 and 16,—reprint (1844), page 36.

Letter from Clarke & Bell, Esqs., Architects, Glasgow.

51 St. Vincent Street, Glasgow,
July 27th, 1858.

We have now had some years' experience of the Patent Hot Water Ventilating Apparatus which you have erected for us at the Old Justiciary Court-House in Glasgow, and at the Justiciary Court-House at Ayr; and we have been so fully satisfied with the result of this system of Ventilation, that we have continued to employ it in the Ventilation of the New Justiciary Court-House recently erected here, and have had much cause to be satisfied in doing so, the effect being entirely successful.

(Signed) CLARKE & BELL.

Robert Ritchie, Esq.

The result of ample experience has fully proved not only its utility and safety, but that the hot-water pipes, even in such exposed situations, have stood the test, without any accident, of twelve or more, and many of them very severe, winters,—and the effect of strong frost has been easily guarded against by keeping on a slow fire during its continuance, and filling the pipes with water saturated with salt.*

In the process here referred to, the air is rarefied by being heated to about 200° F., in a chamber at the roof, by means of hot-water apparatus. Above this chamber a shaft or ventilating chimney is carried as high as conveniently can be, in order to prevent the reflux of the vitiated air, its escape into the atmosphere being aided by means of a turncap, Plate V. fig. 1, to which a large louvre is adapted. This cylindrical turncap, as shown in figure 7, page 59, *ante*, is made of zinc, and revolves by means of a wind vane, always turning its protected surface towards the wind. The rarefaction or partial vacuum of the air in the chamber causes the vitiated air at the ceiling of the apartment to rush towards it, from which the ascensional

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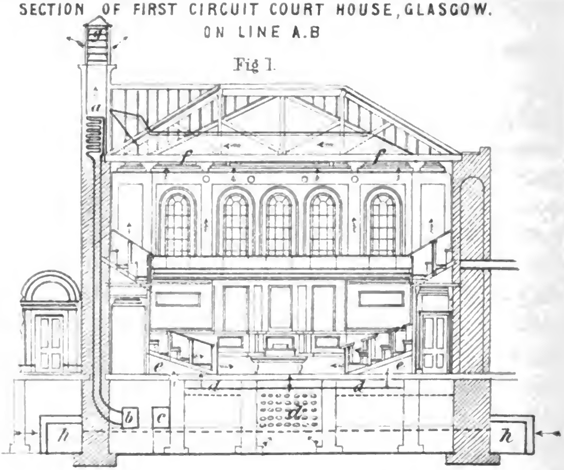
* By recent improvements the apparatus can be so arranged that the water may be withdrawn from the pipes, and these refilled at pleasure.

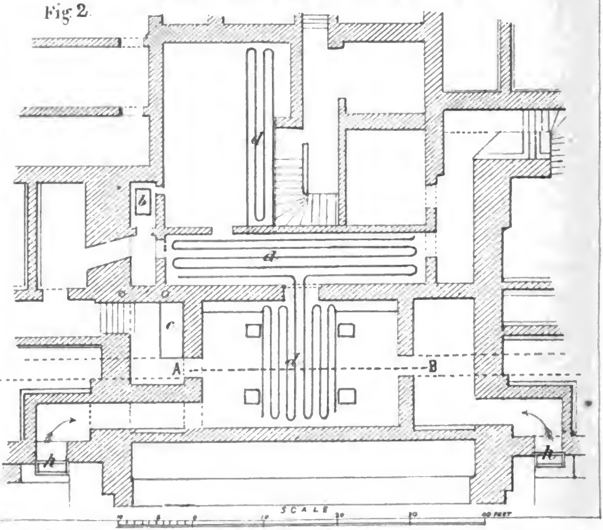
SECTION OF FIRST CIRCUIT COURT HOUSE, GLASGOW.
ON LINE A.B

Fig 1.



PLAN OF SUNK FLOOR OF Dº

Fig 2.



current carries the foul air into the external atmosphere. It is obvious that, by this process, the ventilating apparatus itself cannot deteriorate the air of the apartment, whereas the fumes from a coal fire, or the combustion of gas in the same position, would do so. The success, however, of this plan of ventilation in a great measure depends upon three points: first, the elevation of the shaft or chimney above the heating apparatus, and free escape of the foul air into the atmosphere; second, the egress of the vitiated air from the room at the ceiling, into the hot chamber; and third, the regularity with which the heat is maintained.

In the Glasgow Justiciary Courts, to which reference has been made, an ample supply of fresh air is admitted at the lower part of them, placed under due regulation as to humidity and temperature; and the patent hot-water small pipes have been successfully applied for the ventilation. Plate IV. fig. 1, is a vertical section of the first Court as altered in 1843, and fig. 2 is the plan of the sunk floor of the same, showing the arrangements for warming the Court-House above it. *a* (fig. 1) is the hot-water ventilating apparatus of small pipes at the roof, heated by a furnace *b* placed at the basement of the building, the vertical connecting pipes between these assisting the ventilation; *c* is the hot-water warming furnace. The fresh air is admitted at *h h*, and is warmed before entering the Court, by passing over cast-iron patent screw-joint pipes* of four inches internal diameter, placed in the chambers *d d d* (fig. 2) extending under the body of the Court. The warm air, regulated to humidity, flows into it through numerous small apertures or inlets made in the risers of the seats *e e*, and at other places. A slow upward current is produced by the ventilating apparatus at the roof drawing out the vitiated air at *f f* into a conduit, and expelling it through the louvre *g* into the atmosphere.

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* These patent screw-joint pipes, also the invention of Mr. A. M. Perkins of London, have fully proved their advantages after

Plate V. fig. 1, shows a vertical section, and fig. 2 the plan, of the new Court-House connected with the preceding. This Court is ventilated like the other by an apparatus of small pipes, and is also heated by them. A comparison can thus be made of the advantages of warming with small or large pipes, and the result appears to be that by the use of the small pipes there is a saving in heating, both in time, trouble, and fuel; draughts are also avoided, and greater uniformity of temperature is obtained. *a* (fig. 1) is the patent hot-water apparatus at the roof, heated by the furnace *b* at the basement; *c c* the furnace which heats the warming apparatus. They are separated, but one furnace might have been applied to both purposes if desired. An ample supply of fresh air is admitted to a series of coils of small pipes, *d d d* (fig. 1), placed within the Court-House, but concealed from

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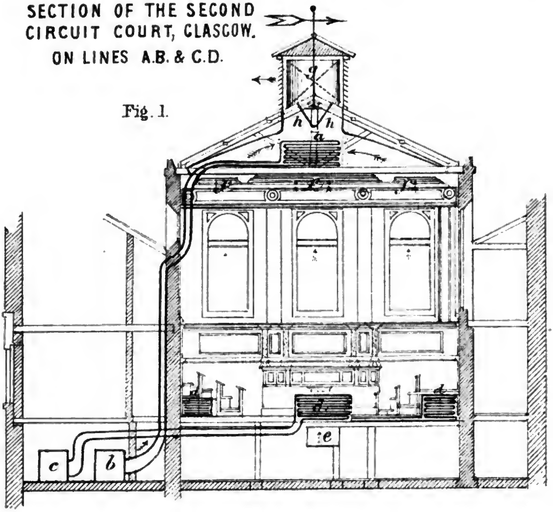
a test of several years experience. By the original plan of heating this Court-House no boiler was used, a portion of the pipes in the furnace constituting the boiler. Mr. Perkins, however, has since introduced a mode (described in Richardson's work, third edition (1856), pp. 61 and 62), by means of which a very small furnace coil of one-inch pipes is made to heat successfully and economically the whole of the large pipes which heat the Court, consisting of several hundred feet.

PLATE V. Page 170

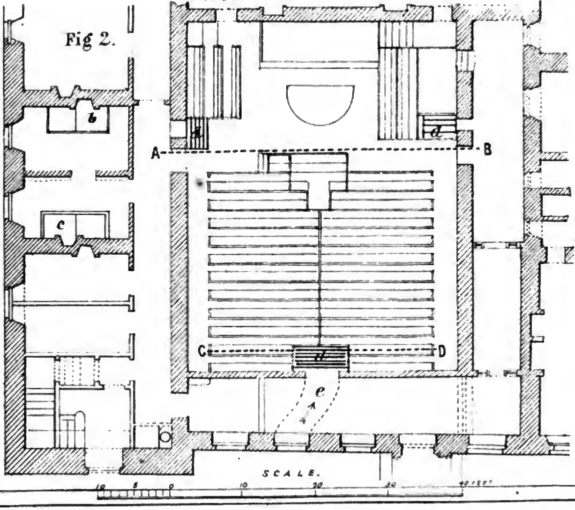
SECTION OF THE SECOND CIRCUIT COURT, GLASGOW. ON LINES A.B. & C.D.

Fig. 1.



GROUND PLAN OF THE ABOVE

Fig 2.



POLICE BUILDINGS, EDINBURGH.

Fig. 1.

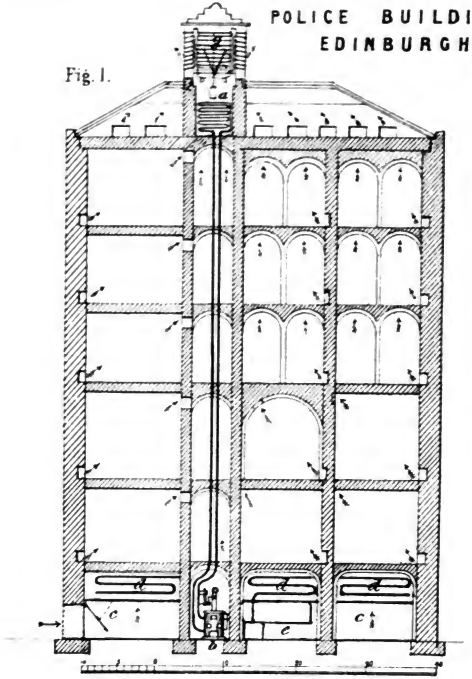


Fig. 2.

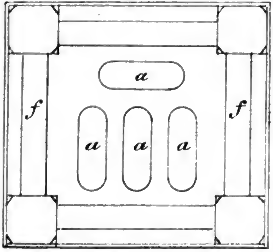
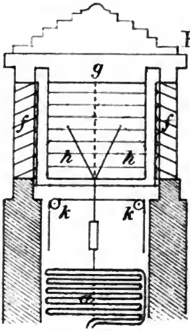


Fig. 3.



view.* The air entering the Court by the conduit *e* under the floor, can be regulated both in temperature and humidity, and adapted to the feeling and comfort of the inmates. A slow upward current of air is produced by the hot-water apparatus *a* (fig. 1) at the roof. The current is regulated by the valves *h h*. The exhaled air is extracted from the Court-House at the outlets *f f*, and expelled into the atmosphere at the louvre *g*,—the escape of the foul air being very much promoted by means of a cylindrical turncap within the louvre, (noticed at page 168,) revolving with its back to the wind by means of the vane, and discharging the foul air to leeward. The velocity of the current may be increased by the elevation of the shaft.

The Circuit Justiciary Court at Ayr has also been successfully ventilated and warmed by the writer in a similar manner, which it is unnecessary further to describe.

Plate VI. fig. 1, is a vertical section of the Police Buildings, Edinburgh, which are ventilated and heated in a manner similar to that illustrated in Plate IV. *a* is the hot-water small-pipe ventilating apparatus at the roof; *b* is the furnace at the basement which heats it; *c c* the fresh-air chamber; *d d d* the warm-air chamber; *e* the furnace which heats the large hot-water patent screw-joint pipes, four inches in bore. The warm air from the chamber is conveyed upwards in one large and several smaller flues, giving off branches to the different floors. The vitiated air from the different apartments on the several floors ascends through small flues which terminate in a long conduit under the roof, and from this the impure air is drawn to the rarefying air-chamber *a*, and passes into the atmosphere through the louvre *g*. The louvre boards *f f* (fig. 2, a ground-plan of the ventilator, and fig. 3 a section of the same on a larger scale, indicate how the wires *k k* are worked at the furnace room *e* at the basement) are made to open and shut, to suit the point the wind blows from, the leeward ones being left open for the discharge. The valves *h h*, which regulate the upward current from the hot-air chamber are also worked from the furnace-room, so that a careful and intelligent person in charge can regulate the whole system of heating and ventilating without trouble. The plan adopted at this building, of heating the cells from the corridors, was that first proposed in the Prison Reports; but it has been found more effective to have separate flues provided to convey the warm air directly where wanted from the hot-air chamber.

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* This is the mode recommended by Dr. Combe in his Principles of Physiology, p. 251, noticed at page 97.

The author of this work having many years ago successfully applied hot-water apparatus to the ventilation of several buildings, cannot but regret that the system he then carried into effect has not been more appreciated by architects, engineers, and the public. This may in some measure be attributed to its expense,—which ought not, however, to be an insuperable objection to a system of proved practical utility.

Other suggestions for the application of hot-water tubes have been proposed. Mr. C. A. Richardson, architect, London, in his work published several years ago on Warming and Ventilation, pointed out the advantages which might be obtained from these applied to ventilating purposes, but which does not appear to have been appreciated. He remarks, (p. 78)—"Mr. A. M. Perkins' system of one-inch tubes becomes, joined to the warming of a building, a forcing power in procuring ventilation in a safe easy manner, such as no other system either of heated water or steam is capable of insuring to the same extent." In the ventilation and warming of a private dwelling the staircase should be the first commenced with. "By placing two or more spare columns of tubing in flues concealed within the thickness of the wall, two flues, or even one flue, properly constructed for the purpose, might be made to ventilate any room of a London house." "The common size flue, 14 by 9 in. is too large for the purpose; it should be divided into two by a half-inch partition, and in each 4½-inch flue is a pipe. Each room should have its separate flue, the whole of which should of course be perpendicular; and as the houses in London are generally two rooms deep, two such groups of flues only would be required: if the two were joined and placed in the centre of the house, having only one outlet at the top opening below the chimneys and carried from them by a funnel, they would be still more effectual." Openings from the apartments are made into these vertical flues about six inches square, which from the high temperature within the flue would draw from the room a constant current of cooler air, thus constantly ventilating the rooms without attention or inconvenience. There is much utility in this scheme, which might on many occasions be judiciously applied; but still, from the want of the general knowledge that forced ventilation is absolutely requisite to produce at all times a current, such a plan has not as yet received the attention it deserved, although perhaps in a few instances which could be pointed out, as at factories, steam and furnace heat have many years ago been advantageously applied in this manner.

Another application of the hot-water tubes or steam pipes arranged vertically and cylindrically or as circumstances admitted, was brought under the notice of the Royal Scottish Society of Arts in 1850, in an interesting communication by Mr. J. Seton Ritchie of London, for which the special thanks of the Society were awarded to the writer. The constant succession of serious accidents in coal mines should induce all scientific institutions to give every encouragement to propositions which hold out the slightest prospect of lessening these deplorable occurrences;—but they are too often treated with indifference. The proposition referred to was to rarefy the air in the upcast shaft by hot-water pipes, cylindrically arranged, either by themselves to maintain a powerful and continuous artificial current, or, when necessary, to be combined with other means to produce a certainty of action and a steadiness in the currents, and so by diminishing the risk of ignition of gases to prevent explosions in mines.

The idea has been more than once revived, and many subsequent propositions have been made, based upon the principle of guarding against explosions in fiery mines, arising from naked lights or open fires (mentioned at Chap. III., Part I., page 131) being in such general use because of their convenience in the ventilation of mines.

In the work of Mr. Richardson referred to, several other illustrations are given of the application of the patent hot-water system to ventilation deserving of notice. In the Lord Mayor's Justice Room, Mansion House, London, (page 87), forced ventilation is produced from these pipes by placing them within a recessed panel lined at the back with glazed tiles near the ceiling of the room, at the bottom of an ascending flue 20 inches square. In this panel there is a series of horizontal tubes. The furnace connected with this tubing is always in operation, both during winter and summer. The air being warmed immediately under the flue, a quick passage of the air from the room passes up it. The current is regulated by a slide running up and down placed in front of the panel, leaving such an aperture as is required, or to be adjusted to the size of the flue above.

Another method has been adopted at the Coal Exchange, London, where the air is warmed at the ceiling of the room with patent hot-water tubes, which are placed at the corner near the ceiling, and are carried round the dome to answer two purposes:—first, the fresh air from without passes over these pipes when entering the building from above to warm the air, while the foul air passes out at the ceiling by another set of openings. There is also a wind-fan worked by hand for summer ventilation, both in this building and in that previously noticed.

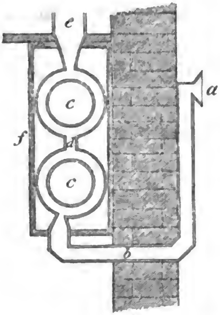
PART II.

VENTILATION BY STEAM HEAT.

Steam can be employed where convenient in several of the applications of hot water which have been noticed. Mr. Richardson, in the last edition of his work (1856), page 89, gives an illustration of the application of steam to the ventilation of the third Criminal Court-House at the Old Bailey. He states "that Dr. Reid had previously been employed by the Corporation of the City of London to warm and ventilate the Old and New Courts in the same building. The system he introduced was the common one, treated on his large and powerful scale. By its use the whole body of air in the two Courts could be changed in a few minutes. The operation practically met with great objection, as the velocity with which the warm air entered the Court, which it did through numerous apertures in the floor, cooled the bodies and legs of the persons standing or sitting above; a sensation of cold being experienced by them although the air introduced was warm. To obviate this, Mr. Bunning, (the city architect), introduced the warm air into the Third Court (which was erected under his superintendence) over the heads of the parties occupying it, letting it enter in large quantities and diffuse itself equally throughout." "The panelling projects from the wall about six inches, and the space thus formed is the passage by which the warm air enters, forced in by the large fan or wheel put up by Dr. Reid for the two other Courts. This fan is 12 feet in diameter and 7 feet in width, and is propelled by a steam engine." "Mr. Bunning made use of the spare steam from this engine for the purpose of warming and ventilating the Court. Mr. Perkins' tubes, instead of being filled with a circulation of hot water, are warmed by the free passage of this steam through them; from the coil in the ventilating chambers above the roof the steam passes into the atmosphere; from that in the fresh air chamber under the court, the steam escapes into the drain. The coils contain about 900 feet of tubing each, which is warmed to 220 degrees, about half an hour after lighting of the fire." These arrangements are said to have obviated the inconvenience which was felt in the other Courts.

The idea of ventilating by steam heat has long been entertained by the author of this Treatise. While hot-water apparatus, fans or pumps, might be applied to one building; to another steam in different ways might be adapted. A good many years ago he brought the subject before the Royal Scottish Society of Arts—and showed several plans by which steam-heat could be advantageously applied, especially in such places as factories, where steam is always present. The Marquis of Chabannes had shown how steam cylinders might be applied for ventilation at the old House of Commons about 1820 (by the foul air passing through tubes in cylinders heated by steam); and Tredgold has shown in his work, (published in 1824), many applications of steam: amongst others, a plan of warming the air, as

Fig. 22.



shown in Fig. 22, where *a* is an external air-tube passing through the wall *b*, and encircling steam tubes *c c*, being confined to act upon them by a case of tinned iron, *d*; and the air being warmed, rises through the pipe *e* into the room. The whole may be enclosed in a wooden case *f*. A pipe of the same size as the pipe *a e* is applied for the escape of the air at the ceiling. The writer's idea of the arrangement of steam-pipe was somewhat different from the preceding, although these plans show how steam may be usefully applied. In his prize paper on the ventilation of ships (1843), published in the Transactions of the Royal Scottish Society of Arts, when noticing different methods of ventilation, it is observed that " the horizontal foul-air trunk which collects the air in one body from the different ramified tubes may be made to pass through a cylindrical boiler of small diameter heated with steam or hot water,*— the extracting pipe simply passing through the steam or hot water, and the foul air escaping at a sufficient elevation." And at page 22, " trunk-pipes conveyed the vitiated air to one large trunk, which might be made to pass through a steam-chest, or encircle the steam-pipe, by which a constant renewal of the entire air would go on."

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* A patent has been taken out for passing hot air through tubes heated by steam, by means of a fan, intended for drying purposes. But the plan of heating the air passing through steam pipes has been long ago practised. See Chapter V.

Fig. 23.

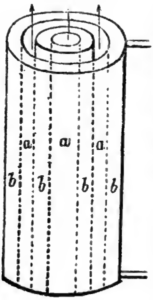


Fig. 23 represents a cylinder for this purpose, such as the writer brought before the Society. *b b*, *b b* are hollow spaces filled with steam, which heats the air in the open vacant spaces *a a a*, through which the exhaled current drawn from the apartments is externally discharged. The ventilator is enclosed and placed above the ceiling.

This plan was again brought before the same Society in a Prize Essay in 1844—(see Trans.) "In factories it is quite possible, in large work-rooms of one story, to make use of the spare steam, or steam admitted into the cylinders *b b*, *b b*, through which the vitiated air *a a a* can be made to pass, at the roof, to facilitate its escape into the atmosphere. This would be a safe, harmless, and economical mode of withdrawing the vitiated air." Also, at page 37 of the same essay —"The vitiated air might pass through the interstices of iron cases filled with steam or hot water; or pipes heated by steam, through which the air might pass, may be employed." From these extracts it is seen what importance the writer of this Treatise attached to this mode of steam ventilation; and so far as can be ascertained, no such plan was proposed or tried until it was suggested and made public through the Transactions of the Royal Scottish Society of Arts.

In a subsequent communication to the same Society, the writer showed how, by combining several of these hollow cylindrical vessels of any required diameter, or steam cases through which a number of air tubes pass, steam might be easily and safely applied to draw out the vitiated air from rooms to the extracting apparatus, or produce a steady upward current from a large apartment.

Another plan he has proposed is to place steam-pipes in a vertical shaft or flue formed in the walls of a house from the basement to the roof, and thus every floor of a tenement might be artificially ventilated, the vitiated air being drawn by the heat into the shaft.

The utility of steam for ventilating purposes might be better appreciated were more consideration given to the waste of it, as already mentioned, in various buildings, such as manufactories, farmsteads, printing-offices, &c. For instance, the blow-off steam, where high-pressure engines are in use, might be conveniently applied through the agency of tubes or pipes in order to produce a continual ascensional current by the rarefaction of the air from heated surfaces, and to draw out the vitiated products from the room and discharge them, like a common chimney protected by a cowl, into the atmosphere. It is unnecessary to enter into minute details. It is sufficient to state that those plans, which the writer of this Treatise submitted to the above-mentioned Society on this subject, were considered deserving of its highest approbation, as the following extract testifies.

Extracts from Report of Committee of the Royal Scottish Society of Arts, on Mr. R. Ritchie's Paper on Mechanical Contrivances for Ventilation. 24th June 1853.

"Mr. Ritchie's Essay, with previous communications,—for which he received the Society's Medals,—form altogether an interesting and valuable compendium of what has been done in the two important divisions of domestic and sanitary economics—Heating and Ventilating—exhibiting the large amount of research which the Author has devoted to the subject.

The compilation may well serve as a guide that Engineers and Architects may consult with advantage when entering upon any application of natural or artificial means of effecting the important objects of heating and ventilating.

An important portion of this Essay is Mr. Ritchie's improvements on the modes for effecting ventilation, that of withdrawing vitiated air by producing a rarefaction of the atmosphere in a vertical tunnel or shaft, communication with which being established from all the divisions of the building.

This object Mr. Ritchie effects by the application of steam-heat (or hot water) applied through an apparatus—producing a rarefaction in the shaft sufficient to effect a current that will ventilate the whole building.

In this arrangement the fire-agency may be situated in the lowest part of the building—the rarefying apparatus acting on the principle of exhausting the vitiated atmosphere of the premises—while fresh air enters from below to supply the exhaustion produced from above. The Working Model accompanying the Essay satisfactorily shows the principles of the invention and its effects.

On the whole the Committee, after mature consideration, have come to the conclusion, that Mr. Ritchie's peculiar mode of acting from above to produce ventilation by the application of steam-heat, is deserving of the highest approbation of the Society, both on account of its safety and economy.

Edinburgh, June 1853. (Signed) James Slight, *Convener.*

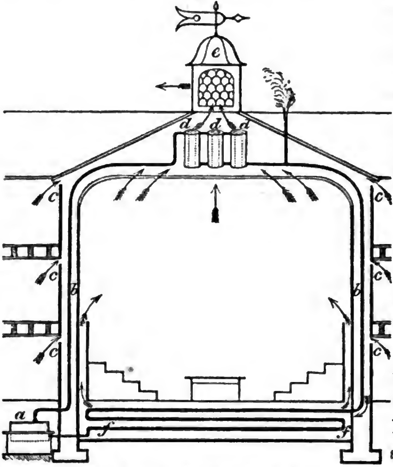
Read and approved of by the Society, 11th July 1853.

(Signed) James Tod, *Sec. R. S. S. of Arts.*"

The applications of steam to produce ventilation by radiation from heated surfaces are safe, easily managed, and free from noise, and the annoyances which the direct application of steam itself causes, to attain this object.

Fig. 24 is a sectional elevation showing the application of steam ventilation by the author R. Ritchie (on the principle referred to in preceding Report) to a hall and apartments on different floors.

Fig. 24.



a is the steam-boiler; *b b* steam pipes placed in a vertical air-shaft or tunnel formed in the walls, rarefying the air within it, and carried from the basement to the roof. A feature of this arrangement is (as mentioned in the Report) that one pipe can be inclosed within another of larger diameter, leaving an annular space between the two, so that there may be steam in the one and air in the other. By this means warm air may be supplied, and vitiated air extracted from different rooms. *c c c*, *c c c* are air outlets from the different rooms into the perpendicular shaft, each room having its separate flue to draw off the impure air, and likewise a fresh-air inlet. *d d d* are the cylindrical steam ventilators as shown in fig. 23, here placed above the ceiling, for extracting the vitiated air from a hall, the air being expelled into the atmosphere by the louvre *e*. The pressure of the steam is avoided by its blow-off into the atmosphere: it is shown for distinctness in the cut, separate from the louvre *e*, but it may be blown through the louvre to aid the upward current. The condensed steam in the pipes is returned to the boiler, and assists in heating the pipes *f f*, which are placed in a chamber at the basement. The fresh air, moderately warmed, enters the hall, as shown in the sketch, by the narrow passages round it, at an elevation of about one third the height of the room. Should the room be over crowded, the air may be forced in by a fan-blower, as will be subsequently described.

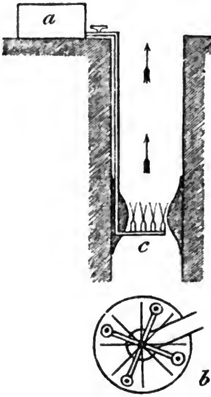
Mr. A. M. Perkins, in a recent patent invention, uses a series of vertical tubes cylindrically arranged for the condensation of steam and distilling purposes. These tubes are one inch in external and three quarters of an inch in internal diameter, and each tube at the top is reduced to a small air-hole, from which a portion of the steam escapes to relieve pressure, the condensed steam being returned to the boiler. The apparatus is simple in its construction, and can be applied with safety and without difficulty. The air which is heated by the condensation of the steam points out the advantages and applicability of this mode of arrangement for ventilation, especially if applied at the roof. In many instances the steam from the kitchen boiler might be similarly economized for ventilating purposes.

PART III.

VENTILATION BY THE STEAM-JET.

It has been shown that the steam-jet which was described by Professor Faraday at the Royal Institution, March 30, 1847, was applied some years ago in the House of Lords, where it has now been given up, it is said from the expense and difficulty of raising a sufficient supply of steam, and from the noise the escape of it created. Indeed the chief recognised use of the steam-jet at the present time is its application to the ventilation of coal-mines, and even for this it has not been much used, although from the evidence given before Parliament respecting it, it appears to have been successful. It has also been suggested that it could be (and there is little doubt of the fact) advantageously applied to the ventilation of drains.

Fig. 25.



The introduction of this contrivance seems to be due to Mr. Goldworthy Gurney, who states in his evidence before a Select Committee of the House of Lords in 1847 on "Accidents in Mines," (page 42), "That in 1824 and 1825 I introduced jets of high-pressure steam as a means of obtaining artificial draught or blast up the funnel of a locomotive engine; therefore my attention was more particularly directed to the application of it to mines. "In 1835" (evidence before a Select Committee of Commons, p. 286), "I suggested it as a means of ventilating mines, in the belief of what I conceived at that time and still conceive to be, the best means of doing it." This mode of ventilation has been described and investigated in the Parliamentary Reports, before referred to, on coal mines. Sometimes the boiler which generates the steam has been placed at the top and sometimes at the bottom of the shaft: if at the latter, in principle it can be little better than a furnace. When applied at the top of a pit, a steam-pipe *c* (fig. 25) is carried down the shaft from the steam-boiler *a*, to a series of jets shown also in section *b*; they are about the size of a goose-quill, and are regulated in size according to the pressure of the steam. When the pressure of steam is 60 ℔s. the size of the aperture is smaller than if 50 ℔s. The jets are placed 18 inches apart, in order that each may take its proportion of the column of air and lift it; and the number of the jets is varied according to what is required to be done. Mr. Gurney states that a boiler of 15-horse power, with a pressure of 50 ℔s., is equal to all ordinary purposes. He considers the exhaustion of air, as respects mining ventilation, by means of the jet to be more convenient in practice than forcing air in mechanically. The advantages of the jet over the fan and the pump are, that it does not require machinery, as they do, to work it; all that is required being merely a high-pressure steam-boiler. Mr. A. M. Perkins' steam-engine boiler, Lord Dundonald's, and boilers on the locomotive principle, which rapidly generate steam, might be advantageously applied for the purpose. According to Mr. Gurney's statements, the force of exhaustion with the jet is very great; the velocity of the current, as ascertained by the water-gauge* and anemometer,† being

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* "The water-gauge consists of a bent tube like an inverted syphon containing water which stands on a level in both legs—one leg is passed into the downcast shaft, and the other leg into the upcast shaft. The water is depressed on the 'in-take' and raised in the other, the difference between the two is the power of the draught. Two inches is considered a powerful current."—*Gurney*, Rep. p. 44.

† There are various kinds of anemometers in use. Those of Dr. Whewell, Mr. Biram, and Naumann, display much skill.

1,909¾ feet per minute, or 21¾ miles (21 miles 1235 yards and 2 feet) per hour.

For many purposes of ventilation the steam-jet is of considerable practical utility. A recent notice of it is as follows (Book of Facts 1858, p. 180): "At the Bowling Iron-works, near Bradford, the steam-jet has been applied in the following manner for ventilating a coal mine. In a pumping-shaft 120 yards in depth, the ventilation of which had been stopped by the water rising at the galleries of the pit, the water having stopped the air-courses, the pit, to within a few yards of the top, became full of the gas known to miners as choke-damp. A perfect ventilation was produced by simply allowing a small jet of steam to issue into the atmosphere a few feet from the top of the pipes through which the water is forced up when the pumps are at work, so that the jet can be worked with perfect safety. The jet of steam issuing from the top of the pipes produces in them a practical vacuum, which draws the foul air up the pipes and thence out of the pit with very great velocity. Wooden or any other pipes may be used. It requires little or no attention to produce a powerful

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Leslie's anemometer depended on the principle that the cooling power of a stream of air is equal to the velocity of the wind. Mr. Lind's anemometer was the indication by depression of water in a tube. Osler's anemometer traces the direction of the wind and its pressure, and is self-registering,—as at the Royal Exchange, London. A simple mode of ascertaining the velocity of a current is to burn a little gunpowder, and to mark the time the smoke takes to travel a given distance. This plan would obviously be dangerous in places where inflammable gases are present.

current, which can be regulated at pleasure. As the steam is discharged into the atmosphere above the top of the pit, it does not interfere with the working of the shaft."

As respects the application of the steam-jet to the ventilation of domestic buildings, the trouble, if not risk, attending the use of high-pressure steam, and the noise it makes in escaping from the jets, renders this powerful agent of less utility; hence it has as yet been little used for the purpose.*

Having now described the various means of obtaining forced ventilation by heat, a few of the methods of aiding ventilation by mechanical agency will be noticed in the next chapter.

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* In the recent Report (1861) on Barrack Ventilation already alluded to, the methods of ventilation by " propulsion " and " extraction " are noticed p. 66; but less importance seems to be attached to them for Barrack and Hospital ventilation than the subject demands. " Ventilation by extraction is in use at the Great Military Hospital at Vincennes, on one side of the Hospital Láriboissière, in the Derby and other Lunatic Asylums, and in the new part of Guy's Hospital, London. It is also in use in most prisons in the country. The moving power in all these cases is heat, either from a fire or from hot-water vessels at the base of a shaft of greater or less elevation." Of steam and the steam-jet no notice is taken by the Commissioners. For Barracks and Hospitals they prefer air-shafts and fire grates " constructed for supplying the rooms with fresh air." These, as applied at the Wellington Barracks, have been described at page 51 of this work.

CHAPTER V.

FORCED VENTILATION BY MEANS OF MECHANICAL AGENTS:—THE FAN, DRUM, BELLOWS, PUMPS, AND OTHER MOTIVE POWERS.

PART I.

FAN-BLOWERS.

THE employment of the fan for giving motion to the air is of great antiquity. The use of the punkah,—which is simply a large fan suspended overhead in the apartment, moved to and fro by a rope pulled by an attendant outside,—is general in India. Steam-power has also been applied to move the punkah. This instrument cannot be recognised as a renovator of air, as it merely acts by agitating the atmosphere within the apartment, thereby inducing a sensation of coolness, the evaporation * from the surface of the body being increased.

The earliest notice of a wind-fan, or blower upon that principle, used in this country, for extracting or supplying fresh air to apartments, appears in a communication of Dennis Papin to the Royal Society of London in 1705 (Trans. vol. 24), who states, in a letter to Dr. F. Slare, that he had improved the Hessian bellows by making the vanes of the fanning-wheel within the case eccentric (fig. 27), in place of

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* According to Dalton's experiments, the hourly evaporation of a cubic foot of water in calm weather is 22½ grains—in a moderate breeze 29 grains—in a high wind 35½ grains.

Fig. 26.

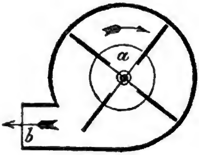
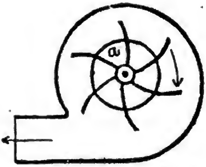


Fig. 27.



concentric (fig. 26); and by working it with his foot he could produce a wind to raise a weight of two pounds. This form of machine is seemingly of much earlier origin than these applications. It is obviously derived from the grain fanning-mill, which is generally supposed to have been introduced into Europe by the Dutch, from the Chinese. In the Gent. Mag. May 1747, a grain fanning-mill is described, seemingly as an old invention used in Silesia. Herbert, in his Encyclopædia, states that the first grain blowing-machine on this principle of which there is a distinct account was that invented by Teral in 1729. In 1723 Dr. Desaguliers brought before the public (Phil. Trans. vol. 39) an account of a machine for changing the air of a room by forcing in fresh air, or removing foul, which he thought would be of great use in hospitals, prisons, and ships, and which he says "was much more effective than Papin's Hessian-bellows." This machine he named the "Centrifugal Bellows." It was merely a fanning wheel or blower, the air entering at the centre and being discharged at the circumference. It was seven feet in diameter and one foot wide. Desaguliers, however, did not adopt Papin's plan of the eccentric vanes, but kept by the concentric form and a number of vanes. It was worked by manual labour. He complained, in 1740, of the difficulty he had in getting a proper trial of his machine in presence of the Lords of Admiralty. It would appear, however, that Sir Jacob Ackworth, Surveyor of the Navy, had one trial on board the Kinsale at Woolwich, but though not present when it was tried, he termed it a philosophical toy. Dr. Ure remarks, that from the defectiveness of its construction, as well as the small area of the discharge pipe, it was probably not misnamed. One of these blowing-wheels or wind-fans on a large scale was fitted up under the direction of Dr. Desaguliers in a chamber over the House of Commons, and it was worked occasionally by hand for ventilating the house from 1736 to 1743. The man who worked it was called "the ventilator." A machine of this kind, it is said, continued in use at the House of Commons for a great number of years.

Wind-fans or blowing-machines have in more recent years been occasionally used for ventilation. But for this method of extracting vitiated air from buildings to be effectual, a motor or impelling force to drive the fans is requisite. From the want of such power, and the expense of obtaining it for domestic buildings, the application of the wind-fan must necessarily be limited. This principle of ventilation, however useful it may be, is more adapted for factories and mines and for buildings where steam power is used. Nevertheless it has been successfully applied at several public buildings. In factories where there is always ample power to drive it, the wind-fan becomes a useful and easily managed means of ventilation; and it is now in common use. In general it is applied to extract the foul air, and is also sometimes used to force in fresh air. But both operations may be performed at once by it.

ECCENTRIC FAN-BLOWER.

A great improvement has of late years been effected by making fanners with iron cases, the vanes being eccentric, as shown in fig. 27,—such as were recommended by Dr. Ure. When the object is to produce a powerful blast, a greater velocity must be given to the fanners, which are constructed much smaller and made to revolve at the rate of about 600 times per minute. Such are the eccentric fans now used at factories and other places, where they are driven by steam power. They extract the foul air with great rapidity, the rate being nearly 100 feet per second, and thus cause a constant renewal of the atmosphere in one or more apartments. It is stated that at a weaving-mill at Manchester where the ventilation had been improved by the use of the fanners, the appetites of the workers were so much increased that they thought themselves entitled to an increase of wages. This is strong evidence of its success.

Regarding the efficacy of the fan-blower for producing an artificial current, Dr. Ure observes that "it has been ascertained that a power equivalent to one horse in a steam-engine will drive, at the rate of 80 feet per second, a fan the effective surfaces of whose vanes, and whose exhaling conduits, have each an area of 18 inches square, equal to that of a large steam-boiler chimney. The velocity of the air in the chimney produced by the consumption of fuel equivalent to the power of 20 horses, was no more than 35 feet per second, while that of the fan, as impelled by the power of one horse, was 66 feet per second. Hence it appears that the economy of ventilation by the fan is to that of the chimney-draught, as 66 is to 35–20ths, or 38 to 1." . . . . "With one bushel of coals consumed in working a steam-impelled eccentric fan, we can obtain as great a degree of ventilation, or we can displace as great a volume of air, as we could with 38 bushels of coals consumed in creating a chimney-draught." . . . . "This mechanical system of ventilation possesses many advantages over the physical. It is infallible under such vicissitudes of wind and weather as would essentially obstruct any chimney-draught ventilation, because it discharges the air with a momentum quite eddy-proof, and it may be increased, diminished, or stopped altogether, in the twinkling of any eye, by the mere shifting of a band from one pulley to another. No state of atmosphere without, or of humidity within, can resist its power. It will expel the air of a crowded room, loaded with the vesicular vapours of perspiration, with equal certainty as the driest and most expansive." *

In the Report (1861) on "Barrack Ventilation &c." before noticed, it is mentioned that one of the most favourable examples of the method of ventilation by propulsion which was brought under the notice of the Commissioners, was that of Thomas and Laurent at the Hospital Lariboissière of Paris,—viz. "two 15-horse power high-pressure engines with fan-blowers attached, which may be used alternately in case

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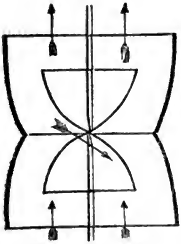
* Dr. Ure—Architectural Magazine (1837), page 171.

of accident to one. The air from the blower is conducted along the arched basement of the Hospital in which the machinery is placed by means of a large plate-iron pipe, from which branches are given off to the different buildings, and the branches are again sub-divided in order to convey air to the wards." "As the air-flues have to pass under the floors, sufficient space is left between them and the ceiling of the room below for an air-trunk of 14 inches deep. The fresh air is admitted to the wards through pedestals in the middle of the floors, and the foul air escapes by openings close to the floor, one between every two beds; which openings communicate with flues in the walls turned up to the roof of the building. It will be obvious at a glance that a plan such as this would be quite inapplicable to barracks," &c.

ARCHIMEDIAN SCREW.

Fig. 28.



Another very important change has been suggested and has been successfully adopted—the Archimedian double-threaded-screw fan. It is to some extent self-acting. The ascensional current of vitiated air acting on the threads and screws makes it revolve. Suppose such a thing were placed in a common chimney or in a ventilator at the ceiling: if not in rapid motion it would be an obstruction to the ascensional movement of the air, and it would rather retard than assist the escape of the heated air into the atmosphere. The double-threaded-screw, like the fanner, to be effective, requires a power to keep it in regular motion, and in this way it has been successfully applied to force air into buildings.

The Barrack Commissioners, in their Report of 1861 already quoted from, state as their opinion that there is "less loss of force in propelling air by the Archimedian screw than by the fan-blower;" and reference is made to Dr. Van Heecke's application of it in the Hospitals Beaujon and Neckar at Paris.* By an ingenious contrivance "the pitch of the screw is made to adapt itself to the velocity of the steam-engine" which drives it, by which arrangement the air-current is maintained at one uniform strength.

Fig. 29.

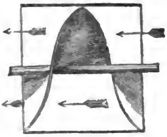
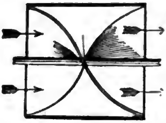


Fig. 30.



Figs. 29 and 30 are different forms as given by Dr. Reid of instruments proposed for the propulsion of air into, and extraction of it from, buildings, for ventilating. The arrows show the manner in which the air passes through. Another form, termed the wind-mill ventilator, consists of blades or vanes turned to the wind.

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* It is stated in the Lancet (1861, page 535), that at a meeting of the Metropolitan Association of the Medical Officers of Health, Mr. W. M. Phipson, C. E., read a paper on Dr. Van Heecke's System of Warming and Ventilation. Besides the buildings above mentioned, this system has been applied to various other places. It is merely the fresh air propelled along an air-channel by means of "a peculiarly-shaped fan (which has been patented) into an air-chamber containing a warming apparatus, where the air is warmed and moistened, and whence it is distributed over the building. The vitiated air escapes from that part of the room at which the temperature is lowest."

EXAMPLES OF BUILDINGS VENTILATED WITH THE FAN-BLOWER.

The Fan-blower by Dr. D. B. Reid has been chiefly applied to the impulsion of fresh air into public buildings. He remarks on the use of it for ventilation—"that he has always found it most economical to use large fanners with a comparative slow velocity, and these have varied, in public buildings requiring a considerable supply of fresh air, from 10 to 20 feet in diameter." Fans of this description have been erected under his directions at the Old Bailey Court-House, London, at the Outer Parliament House, Edinburgh, and elsewhere. In both of these buildings the fans are driven at a slow velocity by small steam-engines on the plenum principle *—the fresh air entering the apartment below, being intended to force out the vitiated air above. The air is

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* In the American Journal of Med. Science for April 1860, Dr. Kirkbride gives an account of Pennsylvania Hospital for the Insane; and amongst other things, the method of heating and ventilating it. The system of warming is by steam-heat, and the ventilation, by propulsion, is effected by the fan. The fan is made of cast-iron. It is 16 feet in diameter, and its greatest width is 4 feet. It is driven directly by the shaft of a steam-engine, and its revolutions vary from 20 to 60 per minute. The fresh air is received from a tower 40 feet high, and is then driven through a duct, which at its commencement is 8½ by 10½ feet, into the extreme parts of the building. From the cold-air duct, openings lead into different warm air-chambers, where the fresh air is heated. The warm air in nearly all cases is admitted near the floor, and the ventilators open near the ceilings. The method of forced ventilation by a revolving-fan was also introduced into the New Jersey State Asylum in 1859.

warmed in winter before being blown in. It does not appear that the force of air blown in is sufficient to expel the air rapidly at the roof without increasing the current so much as to give annoyance, which has been experienced in both buildings. In the Edinburgh one, although there is a large turncap provided at the roof, which revolves with its back to the wind, when the room is crowded it gets overheated, and the fan gives such an impulse to the air at the inlets, as to make a current offensive to those within its range.

ST. GEORGE'S HALL, LIVERPOOL.

Fans on the plenum or impulsive principle have more recently been applied by Dr. Reid as the ventilating medium at St. George's Hall, Liverpool. It is impossible, in a work of this kind, and it is the less requisite, as the subject has been discussed before the Society of Arts, London,* to attempt describing the many contrivances and operations connected with the ventilation and warming of this edifice. It may be sufficient to state that there are furnaces and boilers on the ground-floor which warm the external air by means of hot-water pipes 4 inches in diameter, of which there is nearly a mile. These pipes conduct the hot water from the boilers to the neighbourhood of four colossal wind-fans driven by a central steam-engine of ten horse power. The fans are 10 feet in diameter and revolve at from 50 to 75 revolutions per minute. The air is "tossed amid the labyrinth of hot-water pipes" until the temperature is raised in winter to 90° or 100° F. It is then diffused through the great Hall and Courts by a series of valves and open work inserted in the floors and walls. When not required to be heated, the air is sent into the building by other fans having no connection with the heated pipes or surfaces. The means adopted for carrying off the vitiated air from the great Hall are extensive. The ventilation is on the ascending principle, the fresh air being admitted below and the vitiated air escaping at the ceiling. "The space between the outer side of the arched roof of the Hall and the outer roof of the building is one large air chamber. At each end of the building are placed ornamental and open trellised work, through which the heated air rushes with great force into the upper chamber, and is conveyed away through a series of glass louvre plates into the sides of the elevated roof. In the panels into which the ceiling is divided, there are 20 valves, corresponding to a similar number of ornamental openings in the under side of the ceiling, giving a discharging surface of 400 feet. These valves may be raised or lowered as circumstances require by raising the large wooden flap which covers each of the apertures. There are also a number of side apertures, through which the vitiated air can make its egress in order to reach the vast air chamber at the top of the building. The average temperature, it is stated, at which the Hall has been kept throughout the whole of the concerts, has been about 67° Fahr., varying not more than one degree each way." The object which Dr. Reid had in view was to diffuse as much as possible an equable temperature over every part of the structure.

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* Society's Journal, Sept. 1854. A description was given in this Journal, from notes read by Dr. Reid with special illustrations of the ventilation, April 18, 1855.

The discharge of the vitiated air from the furnaces, and of the waste steam from the boilers connected with the offices and the law-courts, takes place through a series of large horizontal flues terminating finally in four vertical shafts concealed within the angles of the great Hall. These shafts, concealed by columns which improve the appearance of the Hall, are about 14 feet square, having in the centre a dividing wall with apertures which may be closed or opened as required. The smoke from the furnaces and the flues traverses one of these divisions, and the vitiated air from the courts and offices the other. About midway up these shafts there are furnaces for the purpose of creating a draught to carry off these noxious products when the state of the external atmosphere is unfavourable to draught. The horizontal flues connected with these air-shafts admit of several persons walking with ease from one end to the other. "To defend these shafts from the action of varying gales of wind and eddies at the roof, a double provision has been made, consisting of louvres in the interior, and, externally, of large curved deflectors, which turn aside the strongest currents that play upon them."

From this description the vast amount of labour and skill employed may be very easily conceived. The means provided for the ventilation and warming of this large building are so ample, that it cannot fail of success if attended to and worked out in the manner the able deviser has intended. Beside the plenum process of ventilation by large fan-blowers, to trust to which entirely, as has been stated, is often uncertain in its results, it has been combined with the vacuum movement, ensuring a current at all times by means of furnaces placed in the foul-air shafts.

IMPULSIVE AND EXHAUSTING MOVEMENTS COMBINED.

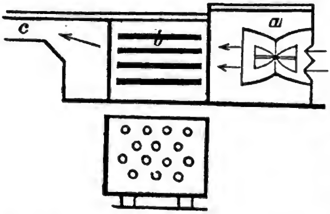
At another building in Liverpool (the Philharmonic Hall), the architect, Mr. John Cunningham, has employed fan-blowers of a smaller description for the ventilation, which act both upon the impulsive and exhausting movement of the air combined. Two fans are used, driven by a small steam-engine. The arrangement of the fans is the same as that recommended by the author of this Treatise in his Essay on the Ventilation of Factories, published in 1844—(See Trans. of R. S. S. of Arts, p. 28.) "I propose to make use of mechanical ventilation in factories by means of a wind-fan, or screw ventilator, or air pump, placed at the bottom of the building in order to throw in a constant stream of fresh air; and to draw off the exhaled or vitiated air by a wind-fan on the upper part of the building,—these two wind-fans being worked either by the steam-engine or other power as may suit best." The architect at Liverpool speaks highly in favour of the plan he has adopted of ventilating with two fans, as by the double or reciprocal action any amount of ventilation can be commanded, and there is not required that amount of impulsive force to discharge the impure air, which is requisite when only one impulsive fan below is applied. Dr. D. B. Reid, in his recent article on ventilation (Enc. Brit. last edition), expresses himself as favourable to compound ventilation "when both plenum and vacuum ventilation may be said to be in operation, the vitiated air being extracted with as much power as that by which the fresh air is forced in. This is the most perfect form of ventilation for all very crowded apartments."

At factories, as yet, wind-fans are chiefly used above to extract the foul air, but the advantages of the combination of two fans under proper regulation cannot be overlooked. Although the certainty of action can never be depended upon unless there is a motive power at command to drive the fan, still, in cases where a slow movement would suffice, a plan might be devised to extract the exhaled air,—as from a school-room, by having a fan or screw worked by weights, wound or drawn up like a clock or jack so as to keep the fan revolving for so many hours at a time, and the fresh air to enter the room at points found most convenient. In the Parliamentary Report on Barracks (1861, p. 66) the same idea occurs. It is stated that it has been proposed to ventilate separate rooms "by small ventilating machines the mechanism of which should be worked by a weight like a kitchen jack." The fresh air could be admitted to these rooms by the air-inlet noticed *ante*, page 159. "This consists of an iron box opening upwards to the ceiling, inserted close to the ceiling of the room, having a direct communication with the external air." R. page 68.

FACTORY VENTILATED WITH THE SCREW-FAN.

In some instances the Archimedian screw has been used at factories for the impulsion of fresh air, as a substitute for the fan-blower. About thirty years ago M. Motte introduced it to public notice. In 1843 the author saw the double-threaded-screw in operation at Leeds in the works of Messrs. Marshall. It was used to propel air into a large power-loom chamber of one floor. It was driven by means of an eight-horse-power engine, and a very strong current was produced. It appeared most effective. In winter the air is heated by being forced by the screw *a*, fig. 31, through a number of small tubes *b*, placed within a large iron case heated by steam (shewn in the section under the transverse one showing the tubes.) After passing through the case *b*, and receiving heat, the air passes into a large flue *c*, and from thence (subdivided) enters the room by numerous apertures in the floor, and the vitiated air passes out by the impulsive or plenum process at the numerous roof lights above. Before the air leaves the chambers where it is heated, moisture is imparted to it by means of a jet of water falling on a circular iron plate revolving rapidly, which sends a sheet of spray upon the entering current of air. These arrangements have been carried out by Mr. Combe of Leeds. The Archimedian screw has also been used for ventilating purposes by, amongst others, a M. Combes in Belgium.

Fig. 31.



The screw applied in this manner proves its utility, and from the rapidity of the motion seems to realize what has been stated, that there is less loss of force by it than by the fan. Another form of machine of this kind, although somewhat different in its details, for which a patent has been obtained by Messrs. Hamilton & Weems of Johnstone, was brought before the public some years since. It consists of a wind-fan driven by steam-power arranged so as to force the air through tubes placed in a case heated by steam, the air being heated in its passage through the tubes before it is discharged. This machine has been chiefly applied to drying purposes, for it can be of little use for general ventilation unless where steam power can be employed. The idea of heating the air in its passage through tubes heated by steam or hot-water has been long since anticipated. Tredgold's plan is shown in fig. 22, at page 178 of this work; and the Marquis of Chabannes and others applied this system many years ago. It is shown from fig. 31, p. 201, that the plan of forcing the air by the wind-fan through heated tubes has been a long time in use.

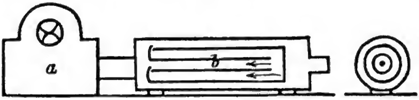


Fig. 32.
a is the fan-blower, and *b* the heating cylinders.

PATENT WIND-FANS OR BLOWERS.

Amongst other forms of the wind-fan there is a horizontal one invented and patented by Mr. G. L. Lloyd, March 1828. There is also a revolving fan of a somewhat similar kind invented by Mr. H. Bessemer, and also one by Mr. William Brunton, C. E. of Newport, South Wales. There is also one patented by Mr. Haig, London, which he terms "a continuous blast-blower well adapted for the ventilation-blast of mines, ships, and buildings." "It may be worked as an extractor, or as an impeller of the air, and it is capable of exhausting from 2000 to 6000 feet of air per minute." In the minutes of evidence taken by a Committee of the House of Commons on accidents in mines, June 1838, there is a plan proposed by a Mr. John Martin of London, for ventilating mines by a wind-fan placed on the top of the upcast pit; but the peculiarities of his ventilating-fan are not described.

FANS IN CARRIAGES.

A patent was obtained in September 1842 by Mr. Robert Hazard of Clifton, near Bristol, for improvements in ventilating carriages, and cabins of steam-boats. He proposed to remove the vitiated air within a carriage by means of a fanner fixed at a convenient place, and set in motion by the revolution of the wheel or by other motive power. This plan could be easily applied to railway carriages, by which the vitiated air could be extracted by the revolution of the carriage wheels without annoyance to the passengers, by placing it, perhaps, on the top of the carriage. He does not specify how he intended to apply his fans to ships' cabins. An excellent paper appeared in the Builder, January 1859, on the defective ventilation of railway and other carriages. It is remarked that a close carriage compartment is some twenty times worse, as regards the means of ventilation, than a prison cell. In a prison cell each occupant has 1000 cubic feet of air space, with a regular change of air by artificial ventilation; but in an ordinary railway compartment, the air space for each person when the compartment is full, will not amount to 50 cubic feet, and, all things considered, scarcely half this.

The very great attention which has been paid by engineers to improving the wind-fan and applying the revolving machines, with the aid of steam power, to forced ventilation, has now been shown. It is only of recent years, however, that the utility of the fan for ventilation has been fully appreciated; but the difficulty in domestic buildings of obtaining a motive power to work such ventilators, renders them of comparatively less use than they really are, or otherwise would be; while even in these applications much care is requisite to prevent the complaint sometimes made against them of blowing hot and cold, or of creating offensive currents.

PART II.

REVOLVING DRUM.

Mr. Brunton's Ventilator for mines and other purposes has been practically tested, as he showed before the Select Committee of the House of Lords on "Accidents in Coal Mines" in 1849. As applied at Mr. Powell's coal-pit (the Gelly Gaer) in Glamorganshire, on the Taff Vale Railway,

it consisted of a revolving drum *a* (Plate VII. figs. 1, 2, 3, 4) 22 feet in diameter, made of sheet-iron, placed upon an air culvert *b* communicating with the upcast shaft *c* of a coal-pit which was closed at the top. There is a circular wall of masonry *d d*, 8 feet in diameter, concentric with the drum, and which reaches to within two inches of the lower part of it. The two-inch space is filled with fire-clay, and it is made sufficiently tight so that by the revolving

W. BRUNTONS COLLIERY EXHAUSTING VENTILATOR

Fig 1.

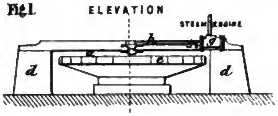


Fig 2.

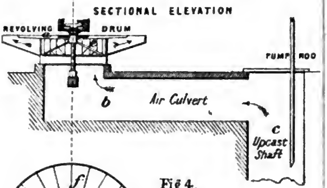


Fig. 3.

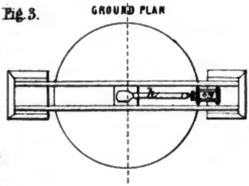
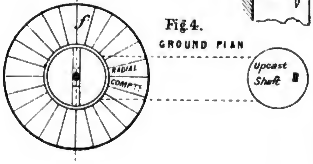


Fig 4.



STRUVE'S PATENT MINE VENTILATOR.

Fig. 7.

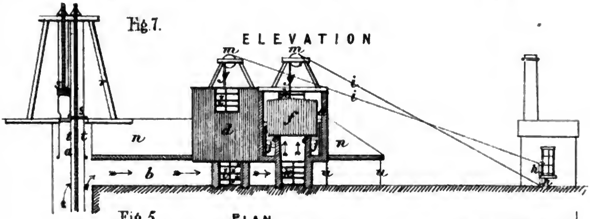


Fig. 5.

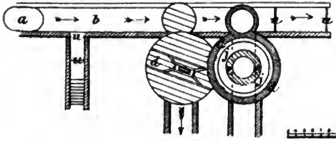
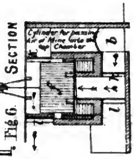


Fig. 6.



of the drum a considerable rarefaction or current is produced with very little leakage. In turning, the drum in its revolutions charges the air through the radial openings *e* with a degree of force which is due to its velocity upon the principle of centrifugal force. The air enters the radial compartments *f* (fig. 4) below, and passes out at the edge. The motive power is a steam-engine *g* (figs. 1, 3) distinct from the colliery engine; the driving pulley being ten times larger than the little pulley *h* on the spindle of the drum, so that if the driving pulley turns 58 times per minute, the drum revolves 580 times. There is an arrangement provided, by a moveable platform, that when drawing coals it opens and shuts as the stage rises or descends.

The drum, if driven 210 revolutions per minute, will produce a rarefaction or drawing power whereby a current is generated producing a pressure of upwards of 50 pounds on the square inch. The expense of the apparatus with a suitable high-pressure engine of a few horses power to work it at 130 revolutions per minute, may be estimated at £150, and with the boiler, at £200.

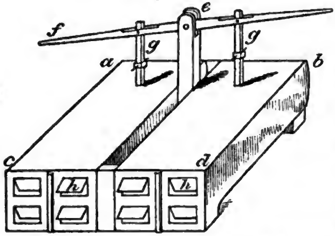
The opinion of other engineers is favourable to Mr. Brunton's ventilating machines. Mr. Samuel Dobson, mining-engineer, South Wales, who had seen the machine in action at Gelly Gaer colliery, states in his evidence before the Committee that he considers it "a much more powerful means of ventilating than the furnace," (p. 420); and "it is stated that from experiments made in presence of practical and scientific gentlemen when the machine was going about 99 revolutions per minute, the rarefaction (as indicated by the water guage) maintained in the upcast shaft was equal to 2½ inches of water, or 13lbs. on the square foot, and this produced a strong current through the workings of the colliery. One of the side ways of 20 yards long had a mean area of only 9½ superficial feet, yet such was the power of the machine that 18,000 cubic feet of air per minute were propelled through the passage at a velocity of 32 feet per second, and afterwards found its way to the upcast pit through an opening of only 4 superficial feet area, at a velocity of 70 feet per second, exhibiting a degree of rarefaction and power of propulsion to the entire satisfaction of all present." "Another experiment was made with the machine by stopping the influx of air from the downcast shaft, and in less than five minutes the whole colliery was artificially subjected to a rarefaction equal to, and in its effect upon the gas in the coal corresponding with, a sudden fall of the barometrical column of about 2-10ths of an inch of mercury." "To this capability of drawing off at pleasure the carburetted hydrogen from the goaves and fissures during the absence of the workmen and their lights, and the reintroduction of fresh air before the men resume work when the colliery will be found in an extraordinary state of purity of atmosphere, the inventor looks with confidence as a means of preventing fire-damp, and promoting the health of the workmen." It was stated that the number of the revolutions of the machine might be increased with safety to 150 or more per minute, which would give a pressure equal to 27·2 upon the square foot. Mr. Brunton says that he could rarefy the air by his machine to the extent of 7 or 8 inches of water, which he never saw done by other means.

PART III.

BELLOWS.

Contemporaneous with the introduction of the wind-fan into this country for ventilation, was that of the Bellows, by the well known Stephen Hales, D. D., F. R. S., Rector of Farrington. In a communication which he wrote to the Royal Society in 1742, he called it the "Ship's Lungs." In his work, now rare, termed "Description of Ventilators whereby great quantities of fresh air may be conveyed into mines, ships, &c." (8vo, London, 1743), he notices the ventilator of M. Triewald,—an account of which was read before the Royal Society of Sweden, 3rd April 1742, and a description of it published by order of his Swedish Majesty, called a "Deduction of the usefulness of his engine on board of Ships," and a translation of the work was communicated by Cromwell Mortimer, M.D., Secretary to the Royal Society, to Dr. Hales. Dr. Hales does not describe Triewald's plan; but in all probability it was on the same principle as that brought under the notice of the Royal Society by the former as the "Ship's Lungs." Triewald's ventilator drew the foul air from under the decks of ships; the least it exhausted was 32,172 cubic feet of air per hour, that is at the rate of 21,732 tons in 24 hours. In men-of-war and hospital-ships, this machine was placed on the upper hatch, and the pipe going down between decks drew out the unwholesome air, which was instantly replaced by fresh. In 1742 all the men-of-war of the Swedish navy were fitted with this apparatus; and in that year the King of France ordered all his navy to be provided with these ventilators. Dr. Hales recommends his own ventilator as being easily and cheaply constructed.

Fig. 33.



It consisted (Fig. 33) of two oblong air-tight wooden boxes *a b c d*, parallel to each other, having wooden boards or midriffs closely fitting their interior section, hinged at the end, and drawn up or pushed down at the opposite ends by means of the upright rods *g g* attached on the standard between the boxes. By the elevation or depression of the midriff effected by the alternate raising and depressing the ends of the lever *f*, the air was drawn in or forced out of the boxes through a series of valves *h h*, some opening inwards and some outwards.

At the opposite end from where the iron rods were, there was a casing placed over four of the valves which emitted the foul air, communicating with an air-trunk or pipe which led off the air in one body. It could be used either to throw in fresh air or to draw off foul air. Dr. Hales describes the application of his ventilator to H. M. ship Captain. The ventilator was about 10 feet long, 5 feet wide, and 2 feet deep. It was placed flush with the floor of the orlop deck, and the trunk, or vitiated-air pipe went through the gun and upper decks near the side of the ship to the top of the gunnel. Two men standing on the orlop deck worked the lever, which was 12 feet long; and from the number of men in large ships the labour was small. The lever and standard were made to unship, so that little obstruction arose from the machine.

When the hold was to be ventilated, the gratings on the upper decks were covered with tarpaulins, and the doors left open of those cabins which wanted ventilation. The ventilators were made of different sizes, according to the class of the ship.

Notwithstanding the success, which was acknowledged at the time, of these ventilators in ships, mines, and prisons; still on shipboard there must have been objections raised against them, as Dr. Hales, in his communication in the Philosophical Transactions 1751–1755, combats these objections, and regrets that the system was not more generally used for the preservation of the health of seamen in ships. Whatever may have been the cause of their discontinuance, and it is more than probable it arose from the trouble of working them, they gradually appear to have been disused in ships, and no vestige of them seems now in existence. The use of bellows for ventilation had but a short duration, and has not again been revived in these inventive times. The operation of these bellows is closely allied to that of the pump.

PART IV.

AIR-PUMPS.

The next class of ventilators are those on the pneumatic principle, such as the various forms of air-pumps, which have been proposed and adopted. But a preference appears to be given to wind-fans, from the steadiness of the stream of air evolved by the rotatory motion.

The idea of using pumps for mining ventilation seems of long standing. It was first proposed by Erasmus King to have ventilators worked by the "fire-engines of mines;" and Mr. Fitzgerald (in Phil. Trans. 1758) suggests an improved method of doing this. In the Transactions of the Society of Arts of London, 1810, Mr. J. Taylor of Tavistock has described a plan of pumping out impure air from mines by an exhausting cylinder. Mr. Taylor's engine discharged more than 200 gallons of air per minute. It was proposed to be worked by a regulated power or weight on the principle of clock-work;—or the pump could be attached to a small fall of water of about 12 feet; or steam-power could be substituted for water-power.

BUDDLE'S AIR-PUMP.

Mr. John Buddle, the well-known mining-engineer, applied the pump worked by steam-power to ventilate a mine. He stated in his evidence given to the Select Committee of the House of Commons in 1835 on Accidents in Mines (page 132), "that the most common way (of inducing a ventilating current) is by rarefaction, which is effected by placing a powerful furnace at the bottom of the up-cast pit; or where it is not safe to employ a furnace, by what is called a water-fall. Both these modes have their advantages and defects; in many instances I have experienced that no furnace could be lighted on account of the enormous quantity of gas coming upon it, which would cause it to explode; that is an objection to a furnace as not being applicable to all cases. The next is the water-fall; that is very good, but yet it is objectionable inasmuch as a sufficient quantity of water could not be thrown down without risking the drowning up of the workings. To obviate this difficulty, between 1807 and 1810 I applied various modes of inducing a current of air through a mine—the steam-ventilator, the hot cylinder, and the air-pump." "In a letter which I addressed in 1813 to Sir Ralph Milbanke, president of a Society at Sunderland for the prevention of explosions in coal-mines, all the different modes are explained." From the evidence of Mr. George Johnston, coal-viewer, in the same Report (p. 84), it appears that the piston air-pump which Mr. Buddle erected at the Heaton and Hebburn Collieries "was five feet square, with a stroke of 8 feet, and the valves were one-third the size of the piston;" and it was worked by steam-power at 20 strokes per minute. Mr. Johnston states that the air-pump was used at Heaton Colliery, but he found it was not sufficiently powerful to cause a proper ventilation of the mine. In spite of the danger of explosions pointed out by Mr. Buddle, it was replaced by the furnace. Mr. H. Wood, coal-viewer, who was called upon by the Committee in 1835 to give his opinion upon the utility of a large air-pump, as also upon a system of fanners upon the winnowing principle, states (page 58) that he had no "knowledge from his own experience of the power of such machines, or the velocity of the current that could by them be obtained." But Dr. N. Arnott, in his evidence before the Select Committee of the Lords on Accidents in Mines (1849), gave an opinion of the value of the air-pump for ventilation.

He states that "there is no limit to the quantity of air which may be moved by it."

STRUVE'S EXHAUSTING APPARATUS.

One of the most successful applications of the air-pump to mining ventilation is that invented by Mr. William Price Struvé, mining-engineer, Swansea, Wales. (Plate VII. figs. 5, 6, 7.) He terms it the "Patent Mine Ventilator."* This machine has been brought more prominently before the public in the evidence given by him to the Select Committee of the Lords in 1849, and before the Committee of the Commons in 1854.

It consists of two pumps or gasometers, which move up and down in a case of masonry. The lower part of this masonry is a tank of water; the water forms the hermetical seal which prevents the air traversing from the inside to the outside of the gasometer."

The air-pumping machine was first successfully applied at the Eaglesbush Colliery, South Wales, and since elsewhere. The expense of the whole, complete, without the steam-engine (which is applied to no other purpose), is about £300. He subsequently estimated the total expense of a 25-feet mine ventilator, capable of passing through a mine 100,000 cubic feet of air per minute when the pistons move at the rate of 200 feet per minute, at £450; and a 16-inch high-pressure engine,—cylinder to work horizontally, with boiler, would cost £250; making the whole expense £700. But if spare steam-power happened to be at the colliery,—by taking steam out of the boiler, and merely having a cylinder to work it, the expense would be brought down to something like £550 to £600. (Par. Rep. 1849, p. 281.)

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* An improvement in the ventilation of mines, more particularly applicable to a new pit, has been proposed by Joseph Jones of Severn Stoke, Worcester. The distinguishing feature of the system is that the downcast shaft is placed at the lowest point of the mine, and the cold air from the surface is carried at once into the lowest parts of the mine, or into the places where the men are at work, whence it ascends without interruption to the upcast shaft, which is on the rise of the seam. The rarefaction of the air in the upcast-shaft is increased by a furnace, or Struvé exhausting apparatus.

Fig. 7, Plate VII. is an elevation showing its application at the pit. Fig. 6 is a section, and fig. 5 the ground plan. *a* is the upcast shaft, *b* is a culvert 5 feet by 6 feet, connecting the upcast pit with the ventilator;—thus an uninterrupted communication is established with the whole of the air passages of the colliery. *d*, *d*, are two cylinders of masonry 14 feet interior diameter and 16 feet high. *e*, *e*, are interior cylinders of masonry 9 feet 6 in height and 4 feet 6 in diameter; the space between the two cylinders is filled with water 7 feet deep, marked *j*, *j*, which prevents air escaping or being admitted except through the inlet or outlet valves. *f*, *f*, are two airometers of 12 feet in diameter and 8 feet 6 in. long, made to balance each other and to move vertically in the water by means of guides;—*g*, *g*, connecting rods with the chains from the cranks, and which also serve as guides;—*h*, *h*, two cranks placed in opposite directions on a shaft, and to which an engine of about 5 horse-power is attached to give them rotatory motion;—*i*, *i*, two chains connecting the cranks with the airometers and giving a vertical motion to the airometers;—*k*, *k*, *k*, *k*, four air-ports 4 feet square fitted with valves to admit air from the mine;—*l*, *l*, *l*, *l*, four air-ports 4 feet square, with valves for the discharge of the air into the atmosphere. *m*, *m*, are the framings which support two sheaves of 2 feet diameter, over which the chains move, and which have to support the whole weight of the airometers. *n* is the embankment formed from the cuttings of the foundations. *r* is the framing of the pit for raising coal, showing the cover *s* raised by the waggon, the platform of the waggon supplying its place. *t*, *t*, are tubes at the top of the pit to prevent leakage;—*u*, *u*, *u*, doors through which the apparatus may be inspected.

The pumps are double-pumps, there are four outlet-valves and four inlet ones; an inlet and an outlet to each pump. The machine is attached to the top of the shaft which creates the ventilation of a colliery, and is worked by a steam-engine of 5 horse-power. It has two airometers or gasometers of 12 feet in diameter, each capable of being worked to a four-feet or a six-feet stroke. If they were moved at the rate of 200 feet the apparatus would discharge 40,000 cubic feet of air per minute. The outside of the machine is made of masonry, the top is covered with wood. In working the apparatus, two sets of valves, working together, open at the same time; each valve being about equal to 16 superficial feet. So that there are 32 superficial feet open to receive the air, and 32 superficial feet open to let the air out of the mine. So that as they are working together, whilst the one is filling with air from the mine in its interior, the other would be filling from the air of the mine in the exterior chamber.

Mr. Struvé states in his evidence (p. 252) that the apparatus at the Eaglesbush Colliery is worked by a small engine of 5 horse-power; and it is one of those collieries difficult to ventilate on account of the size of the upcast shaft, which is only 3 feet 6 inches in diameter and is only about 8 fathoms deep. Through this small diameter 13,000 cubic feet of air are driven per minute, the engine not being sufficiently powerful to do more. This creates a rarefaction of about 2⅜ inches on the average, which is equivalent to about 12lbs per square foot. The machine at Eaglesbush makes, with a 4-feet stroke, 7½ strokes in a minute.

OLDHAM'S FORCE-PUMP.

Mr. Oldham, engineer, London, has applied a force-pump for ventilating purposes combined with warming. He has put this system in practice at the Bank of England and Bank of Ireland; and it was decribed in the Civil Engineer and Architects' Journal for 1839.

A body of pure air of any required volume, and passing at any required velocity, is forced by the aid of an air-condensing pump into a chamber or chest, where it is heated, by an ingeniously-contrived but extremely simple apparatus, by means of cross currents of steam. The peculiarity of its contrivance is, that an ascending body of air, on entering the chest divides itself into any required number of thin horizontal films, by which a very extended surface is exposed to corresponding steam-heated metal surfaces. The chest or condenser in the apparatus at the Bank of England is 3 feet square, and the body of the air to be heated, while passing over 3 lineal feet, spreads itself over 154 superficial feet, and coming in contact with a corresponding superficies heated by steam, receives a very large supply of heat in a short space of time. This apparatus at the Bank of England, besides heating and ventilating several large apartments, is subjected to the test of evaporating, from a series of 400 large mill-boards having a surface of 1600 feet, the moisture which they have absorbed from the freshly-printed bank notes, large quantities of which are thus dried daily by this process. By Mr. Oldham's arrangements the air is filtered and purified before entering the interstices of the steam chest to be heated, and can also be regulated in temperature. The author has seen it in operation.

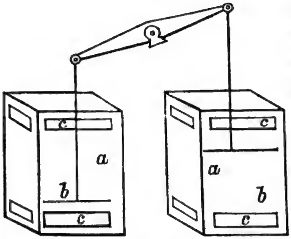
DR. ARNOTT'S AIR-PUMPS.

Dr. Neil Arnott of London, in the Parliamentary Report of 1849, p. 86, appears to give a decided preference to the air-pump over other mechanical contrivances for forced ventilation. He says (page 91) " one of the chief advantages of the pump as compared with other means is, that it measures the quantity of air passing along so intelligibly to even the ignorant and careless observer, that it keeps all on their guard against possible dangers from unsuspected impediments, &c.; a positive obstruction would stop the pump, but might make no visible change on the action of a chimney, a fan-wheel, or a steam-jet." " The whole question of ventilation is in reality a question of comparative quantities or measures." Now " that pumps can be made with curtain valves, which offer no sensible impediment to the passage of the air, we find that the same quantity of air may be moved by the eightieth part of the force which Dr. Hales had to employ."

Dr. Arnott also states that there are various simple means of accomplishing ventilation even on a large scale, as in mines, and at the same time providing for the admeasurement of the amount of air supplied; but the means he thinks the best adapted for general purposes is a form of air-pump. It bears a considerable resemblance to the air-bellows of Dr. Hales, only that it has the advantages of steam power to work it. Whilst this gives it a certainty of action, it no doubt has the disadvantage that if steam power be necessary to work it, it is thereby limited in the extent of its general application. Dr. Arnott's pump is described in the Parliamentary evidence before referred to, and was introduced some years ago at the Brompton Hospital for Consumption. The author has there seen it in operation; but after a trial of some years, from one cause or another it has been removed, probably in consequence of the trouble attending the working of the steam-engine, or from the irregularity in the movements of the air thrown into apartments which require the utmost uniformity of temperature and avoidance of currents. The means of ventilation at present adopted at that Hospital is an extracting fire-apparatus causing rarefaction of the air at the roof.

It may be useful to give a short description of Dr. Arnott's pump, which has met the fate that befell the machine of Dr. Hales, to whom he refers. It consisted of two wooden barrels *a*, *a*, three feet square and six feet deep, with light pistons of wood *b*, *b*, less than 3 feet square, moving loosely up and down the middle of the barrels, but as close to the walls of them as possible without producing wasteful friction. Curtain valves *c*, *c*, *c*, *c*, occupy the spaces above and below the piston. The two pumps are connected with the ends of a beam moving like that of a steam-engine 20 strokes per minute in obedience to a crank.

Fig. 34.



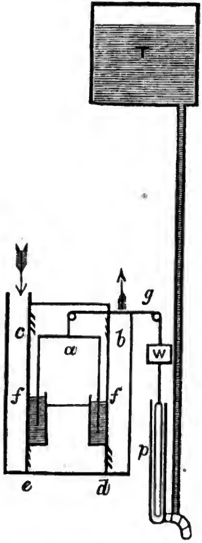
By means of this double pump, 2000 cubic feet of air have been measured into the Brompton Consumption Hospital every minute, day and night, in winter and in summer. The air was warmed in winter, by passing between the interstices of copper plates or leaves heated by hot-water before being pumped in. The pump was worked by a small steam-engine of one-horse power. This plan of imparting heat to the air much resembles those of Mr. Oldham, Mr. Price, and others, who have applied cases filled with steam or hot water, instead of using pipes.

Dr. Arnott says that this pump was in use for some years with success, and that the air is pumped through different parts of the house, every room receiving its due portion by means of air-meters and valves placed at the entrances. The greatest distance the air was conveyed at the Hospital was 150 feet; but he mentions that at the new Marine Barracks at Woolwich, which are about 700 feet long, an apparatus of this kind had (in 1849) been two years in use. The air-pumps in the latter building have pistons of 4 feet square and 4 feet stroke, and are adjusted to give 4000 cubic feet of air per minute as the supply for 1000 men. The driving engine is two-horse power, with a slow movement of 16 double strokes per minute. The cost of the whole was from £300 to £400.

ARNOTT'S WATER-DRIVEN AIR-PUMP.

Another form of an air-pump was planned by Dr. Arnott for the York County Hospital, where 100 patients are each supplied with 20 cubic feet of air per minute, or 2000 cubic feet per minute for the whole house. This plan is described in the same Report (1849.) The machine consists of a pump upon the gasometer principle. A suspended cylinder of thin plate *a*, to hold 500 cubic feet, is made to move up and down twice in a minute—is balanced over pullies by means of a counterpoise w. The mouth of the cylinder dips into water like a common gas-holder, but having an enclosed space above it, *b*, *c*, *f*, *f*, so that it expels its bulk of air equally in rising and falling. The air passes through curtain valves near *d* when falling, and near *b* when rising into the entrance of the distributing channel *d*, *f*, *b*, *g*, and air simultaneously enters the pump at the other side of the corresponding entrance-valves near *c* and *e* from the channel *c*, *f*, *e*, by which the pure air approaches the pump. The moving power is the force of the water descending from a tank T near the roof. This water, after doing the pumping purposes, is used for the general purposes of the house. The water acts on the piston of a small water-engine or pump *p*, in which friction is avoided by its having a mercurial joint for the piston, like the water-joint of the great air-pump *a*. "The pump is self-regulating, and opens and shuts its valves as needed at the top and bottom of its stroke. The air is distributed by channels branching over the house and tapering as they have less air to carry, so that the warm air in winter may not cool by stagnating. A channel of 12 feet square suffices for the whole air departing from the pump through the curtain-valves of that area. The fresh air in cold weather is warmed by two self-regulating

Fig. 35.



water-stoves capable of heating about 800 feet of surface of water-leaves, such as were used at Brompton Hospital. The open fires in the wards should be supplied with fresh air by direct communication between them and the outside." This air-pump is favourably noticed, page 66, by the Commission on Barracks and Hospitals, 1861.

PART V.

DIFFERENT MOTIVE POWERS.

Various mechanical contrivances for ventilation which require a moving force to propel them have been described in this chapter. Steam power has been chiefly noticed as the most convenient and the steadiest of action, and most to be depended upon as a motive power; besides which, the steam-engine is generally in use at those places where forced ventilation, whether by adaptation of fans, pumps, or other means on an extensive scale, is required. There is, however, nothing to prevent, in some situations, other prime movers of machinery being employed for this purpose, such as wind, water, horse, manual, and perhaps electro-motive power, in order to work fan-blowers or other machines for ventilation, as may be regulated by circumstances. In certain situations wind may be made available for the moving force, and water-power in a similar way in other situations. It has been stated at page 219 of this work, that Dr. Arnott has ingeniously applied the force of water for pumping air for ventilation, and other applications of this force could readily be made. A water-fall, although not acting as a prime mover of machinery, has been found a convenient form of effecting ventilation to a certain extent in coal-mines. An artificial decrease of heat is produced in the descending column of air by means of water. A simple fall of water through the pumping pit, which is the downcast shaft, has a mechanical tendency to drive the air before it.* Both horse and manual power are sometimes made use of for driving mechanical ventilators such as wind-fans; but these can only be received as temporary expedients, and are not suitable in many points for permanent purposes.

ELECTRO-MAGNETISM.

Electro-magnetism has been brought forward as another prime mover of machinery; but the anticipations formed as to its utility, wonderful as these electric powers are in bringing all parts of the world into communication, have not yet been realized. A patent has, however, been obtained for its application as a motive power. By this motor, wheels have been made to revolve rapidly, but the "efficiency of magnetic attraction diminishes according to the law of the inverse square of the distances of the surface of the magnet and armature, so that whatever the power to prevent separation when the two are in contact, their mechanical tendency to approach each other deserves little consideration. It is the latter, however, alone, that can induce rotation, or become a source of mechanical effect; so that there is in the very source of the new power a cause of feebleness over which no mechanical ingenuity can ever prevail." (Nichol's

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* Par. Rep. 1849, pages 115, 171, 284; also Par. Rep. 1854.

Cycl.) A difficulty is thus presented in the application of electro-magnetic power which does not seem likely to be soon overcome.

In the meantime, the uncertainty which attends the use of these motive powers, and especially the little dependence which can be placed on wind, has led to very general and extended use of steam-power wherever an impelling force is required to drive machinery.

Before concluding this work, as an abstract of some of the more important subjects treated of may be found useful, the following Summary is subjoined.

So many different contrivances, mechanical or other, prominently brought forward in recent years to accomplish forced ventilation, have been noticed, that we refrain from describing more. There is sufficient to show the great interest which has been taken in this important subject, related as it is with social economics, and enough has been said to enable any one to judge of the comparative advantages or disadvantages of the various processes proposed, and to enable a preference to be given to that which can be best applied to the purpose.

SUMMARY.

In regard to general ventilation, the following conclusions appear to result from the previous investigations:—

1. That a copious supply of fresh or pure air is indispensable for sustaining life;—

2. That for the renovation of the air the establishment of a current is at all times necessary, and that this cannot be obtained in close places unless a constant escape of the vitiated and entrance of fresh air, are provided for;—

3. A slow current may be induced by taking advantage of differences in temperature, or by artificial means;—

4. That breathing impure air is injurious to the healthy existence not only of the human race but of the lower animals, for the proper arterialization of the blood is dependent upon pure air. Impure air is generated in close places by animal respiration and cutaneous exhalations, by combustion of gas or fuel, by putrescent effluvia from animal or vegetable matter, by odours from cesspools, closets, or defective drains, &c.;—

5. That a street, or locality, or tenement, may be contaminated by the vapours arising from untrapped drains communicating immediately with a sewer, or from sinks and gullies. Thus a poisonous or fever-loaded atmosphere may shed its baneful influence upon animal life, and occasion the propagation of disease. Effluvia arising from open drains and garbage and

decayed organic emanations and dung-pits and undrained dwelling-houses, must all prove injurious to health, as has been fully proved by the Registrar-General's Reports;—

6. Salubrity of site is all-important as respects health, which is evidenced by the rate of mortality in different places;—

7. The air of hilly countries and of the sea-side is considered purer and more salubrious than the air of other places. This is supposed to arise from the atmosphere containing more ozone (one of the two forms which the oxygen in the atmosphere assumes), which by quickening the processes of oxidation, so important for health, acts beneficially on the human system. In many large towns the great amount of carbonic, sulphurous, and other gases, produced by combustion, is detrimental to health;—

8. Various analytical processes have been proposed for detecting atmospheric impurities. A very delicate test is required. Dr. Angus Smith* has used permanganate of potash successfully, and it has been applied at various places, so as to bear upon the discovery of the hidden sources and finest shades of contamination. He has shown that the air in a crowded railway carriage is as impure as the effluvia from a sewer;—

9. The great mortality arising from diseases of the respiratory organs directs attention to the question how far these may be influenced or even greatly aggravated by impure air. Statistics have shown the fact that by consumption (phthisis), bronchitis, and pneumonia,

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* A valuable paper "On the Air of Towns" has been published by him recently in the "Quarterly Journal of the Chemical Society."

100,000 die every year in England alone, being one-fourth of the entire mortality;—

10. That the young suffer from impure air, and that the seeds of disease are laid by living in the close ill-aired localities of cities and other places;—that the life of many an artisan is shortened from carrying on his daily employment in impure air, in addition to the aggravation from the employment itself. Dress-makers, milliners, tailors, shoemakers, printers, workers in factories, miners and others, may be mentioned in illustration of this, and Mr. Chadwick has shown that amongst the working classes habits of intemperance are increased by their being compelled to work in a close and confined atmosphere: hence excess in strong drink becomes an additional cause of disease;—

11. In ordinary domestic dwellings, advantage should as much as possible be taken of the natural movements of the atmosphere by the use of doors and windows, to aid in the expulsion of the vitiated air, and to effect a renovation of it within the apartment—and in summer as well as winter the common fire-place becomes a useful auxiliary, though an imperfect one, unless combined with other means.

12. That where artificial atmospheres are required, the heating medium to be employed is a matter of importance. That stoves of all kinds, which do not provide against the entire separation of the products of combustion from the air which they heat, are generators of poisonous gases;—and that stoves in which there exists the liability of overheating the air, and

roasting the particles of matter floating in it, are pernicious to health;—

13. That in crowded apartments, spontaneous or natural ventilation cannot be relied on;—and in many circumstances no thorough ventilation can be obtained unless forced ventilation is applied;—

14. Although much difference of opinion exists as to whether an ascending or a descending removal of vitiated air is the best method to adopt, still, as the ascending movement of the air is the natural one, advantage should be taken of it to remove impure air as it is generated;—

15. That of the many artificial contrivances the choice must be limited in most instances to a process which does not require a motive power to drive it;—

16. Of the modes which require little attention in management, or where no motive power exists, forced ventilation may be obtained, and an uniform current by rarefaction created, by the heat of water or of steam. The same or even a more powerful effect is produced by the steam-jet;—and these means avoid the products of combustion being mixed with the ventilating current;—but in the application, care must be exercised to adopt a safe and proper position for the apparatus;—*

17. That open fires or gas-heat at the roofs of buildings can be applied to effect this purpose; but by these the risk is incurred of the products of com-

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* Plates IV. V. and VI. well illustrate the positions in which the ventilating apparatus may be placed. In such a central one as is shown in Plate V. fig. 1, page 170 (also in fig. 24, p. 182), care must be taken to provide that no risk can arise from the derangement of the apparatus.

bustion being refluxed into the apartment, and being inhaled;—

18. That all artificial plans, such as smoke-pipes placed in ventilating conduits, and other contrivances, which run the risk of sending impure gases into houses, are pernicious and should be avoided, because they are in principle objectionable, and frustrate the object of removing the vitiated air;—

19. Any method having a tendency to send back or return the exhaled air into an apartment is pernicious in principle: hence the sending of fresh air into a room from the ceiling mixed with the products of respiration is injurious to health;—

20. Where a motor exists, such as steam-power or water-power, at a factory,* a public building, a mine, or in a steam-ship, the fan-blower and screw present simple and readily available agents to produce a determinate movement of the air which can be easily regulated and applied advantageously both for impelling air inwards or extracting it outwards;—the wind-fan has been applied to the ventilation of coal-mines both in Belgium and in England; and in the latter Biram's patent fan has also been used.

21. More attention should be bestowed upon the ventilation of ships and steamers carrying passengers than has hitherto been the case. Much attention was paid to this subject many years ago by Sutton and Hales, and more recently by Reid and others;—but the subject does not seem to receive the consideration it deserves, for the old wind-sail appears to be the general plan still in use for the ventilation of ships, and even

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* An Essay on Factory Ventilation by the author is noticed at page 39 of this work.

of steam-vessels, notwithstanding that they so readily admit of a systematic process of ventilation;—

22. In coal-mines, where the importance of ventilation cannot be over-estimated, several mechanical and artificial contrivances deserving of attention have been described. These have already been brought under public notice with the laudable motive of trying to obviate the risk of the explosion of inflammable gas (carburetted hydrogen) in fiery mines,* the danger from such explosions being increased (as stated in the evidence given before Parliamentary Committees in 1835, 1849, 1854, &c.) by the use of open fires or naked lights placed at the bottom of the upcast shaft which are so generally used for the ventilation of coal-mines. This led to the introduction of the "dumb-drift" so as to convey the return-air over the furnace. At page 126 of this work, the importance of ventilating coal-mines by means of two shafts has been fully described. The late Mr. G. Stephenson recommended and adopted two shafts in preference to one large one divided by brattices, or partitions. The evidence laid before Parliamentary Committees was to the same effect, and there can be little doubt that the consequences of the dreadful accident from the brattice being accidentally destroyed at Hartley Colliery in January 1862 would have been prevented had there been two shafts, an up and a downcast one, to the mine.

23. In the evidence given before a Committee of

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* Another accident has occurred, February 1862 (since these pages were written), at Merthyr Tydvil, by which 50 lives have been sacrificed.

the House of Commons in 1854, the value of the steam-jet is fully established from its application to several coal-pits, more especially at that time to one at Seaton Delaval. The Committee of 1852 reported in its favour; but the Committee of 1854, in their fourth Report, while admitting that good ventilation was produced by the steam-jet, reported that the preponderance of evidence was in favour of the furnace;—

24. Of the many mechanical contrivances the same Committee of 1854, while wishing to avoid enforcing any particular system of ventilation, were favourably impressed with the value of Struvé's machine, "especially in shallow pits and level collieries," which had been materially improved since it was brought to the notice of the Committee of the House of Lords in 1849.*

25. Besides Struvé's exhausting apparatus for the ventilation of mines, Brunton's revolving centrifugal drum was tried in 1849 at the Gelly Gaer colliery, and the experiments made with it were considered satisfactory. These machines require a driving force to work them, but plans have been proposed to avoid the risk of accidents in coal-mines from the use of the furnace, by rarefying the air in the upcast shaft by means of hot-water or steam-pipes (described in these pages, p. 174);—

26. That the whole system of mining ventilation requires the exercise of constant vigilance there can

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* D. Landale, Esq., mining-engineer, Edinburgh, in his evidence given before the Commons Committee (Report, p. 11) in 1854, says—"In Scotland we have very little fire-damp in the coal-mines, and where it exists, the furnace is resorted to;" where it does not, natural ventilation, he states, is found to be sufficient.

be no doubt, and every encouragement should be given to judicious inventions or propositions made for improvement by which an employment carried on in a close, warm, and humid atmosphere, where carbonic acid, carburetted hydrogen, and other mephitic gases, exist, may be rendered more salubrious, and accidents by explosions and choke-damp prevented, by which so deplorable a waste of human life arises. The Select Committee of the House of Commons, in their fourth Report, June 1854, recommend "that no colliery should be without some artificial means of ventilation;"—

27. The question of hospital, poor-house, and asylum ventilation has been considered; and it does not appear to have made much advancement on a systematic plan;—

28. Prison ventilation has received great consideration, as the numerous Parliamentary Reports show. But the change of arrangements indicates an indecision which is singular; for sometimes fresh air may be seen entering at the top of the cell and sometimes at the bottom;—

29. Barrack ventilation, and hospitals connected therewith, from their reputed unhealthiness, have recently drawn much public attention towards them, and the lately published able Reports show that the subject is receiving careful investigation and consideration;—

30. In lunatic asylums great improvements on ventilation have been adopted and recommended in recent Reports. Still so much uncertainty surrounds this subject, that by some open fires are adopted, and whilst one authority advocates previously heating the air and throwing it into wards and corridors, and

allowing the rooms to draw air from the corridors, another would convey the warm or cold air direct into a room or a cell, while many condemn as unscientific and insalubrious the plan of warming and depriving the air of its elasticity and density before it is admitted into the building. Some think that the heating media should be placed where the heat is wanted, while others admit fresh air at the ceiling, and draw it off at the floor. Some draw the exhaled air down, causing the liability of its being re-inhaled, while others more prudently draw it upwards, giving a constant supply of fresh air below;—

31. The great amount of oxygen abstracted from the air by the respiration of animals points out the necessity of providing good ventilation in stables and cattle-houses;—the common disease of pleuro-pneumonia amongst cattle must be influenced to a great extent by vitiated air;—much neglect and uncertainty, however, prevails as to the ventilation of these buildings. The subject requires great attention;—

32. Many additional applications of ventilation might have been noticed in these pages, but the object has been not to unduly extend this volume, such as the ventilation of light-houses, drains, &c. The ventilation of railway and other carriages has been alluded to at page 203.

33. From the various plans and contrivances which have been described, the public has an opportunity of understanding the real question at issue, and judging for themselves not only as to the effect of ventilation, the consequence of its being neglected, and the misapplication of this hackneyed word, but as to the negli-

gence that has long existed and still exists in having a proper and thorough system of ventilation incorporated with the structure of a building where many people are crowded together in close apartments. Instead of which, how frequently is it found that openings are made in the ceiling of an apartment, or that roof air-escapes are placed on a building in the expectation that the vitiated air will escape into the external atmosphere;—whereas a direct blow-down current of cold air, to the annoyance of all within its range, is frequently the result, but it has been shown (p. 99) that the principle of such a mode is erroneous. The great advance which practical science has made since physical principles in modern times have become so generally recognised, calls for attention to a systematic arrangement being made in the construction of every building, whereby a pure supply of atmospheric air may be provided, regulated in temperature, and without annoyance to those in it.

It is to be hoped that this contribution to the science of ventilation, will tend to advance general information on the subject, and give more correct ideas upon matters on which so much dubiety exists, and lead to more enlightened views by which comfort and health may be promoted.

FINIS.

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